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Aruga et al.

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(54) **OPTICAL DEVICE AND ILLUMINATION DEVICE**

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Jun. 27, 2019 (JP) JP2019-119943

(51) **Int. Cl.**
F21V 7/00 (2006.01)
F21Y 115/10 (2016.01)

(52) **U.S. Cl.**
CPC **F21V 7/0091** (2013.01); **F21V 7/0033** (2013.01); **F21Y 2115/10** (2016.08)

(58) **Field of Classification Search**
CPC F21V 7/0091; F21V 7/0033; F21V 5/005; F21V 5/008; F21V 5/02; F21V 5/046; F21V 7/0025; F21V 7/0008; F21V 13/04; F21Y 2115/10

See application file for complete search history.

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(57) **ABSTRACT**

An optical device includes: a first reflective surface disposed to reflect, to a substantially arc-shaped first region around a first axis, at least a portion of first light incident along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis, the first reflective surface including a plurality of reflective arc surfaces separated in a direction along the first axis; a second reflective surface and a third reflective surface intersecting each other on the first axis and disposed such that the first reflective surface is located between the second reflective surface and the third reflective surface; and a light-transmissive emission surface adapted to refract at least a portion of light reflected by the plurality of reflective arc surfaces to emit the light around the first axis, the emission surface having periodic irregularities in a cross section in the direction along the first axis.

21 Claims, 33 Drawing Sheets

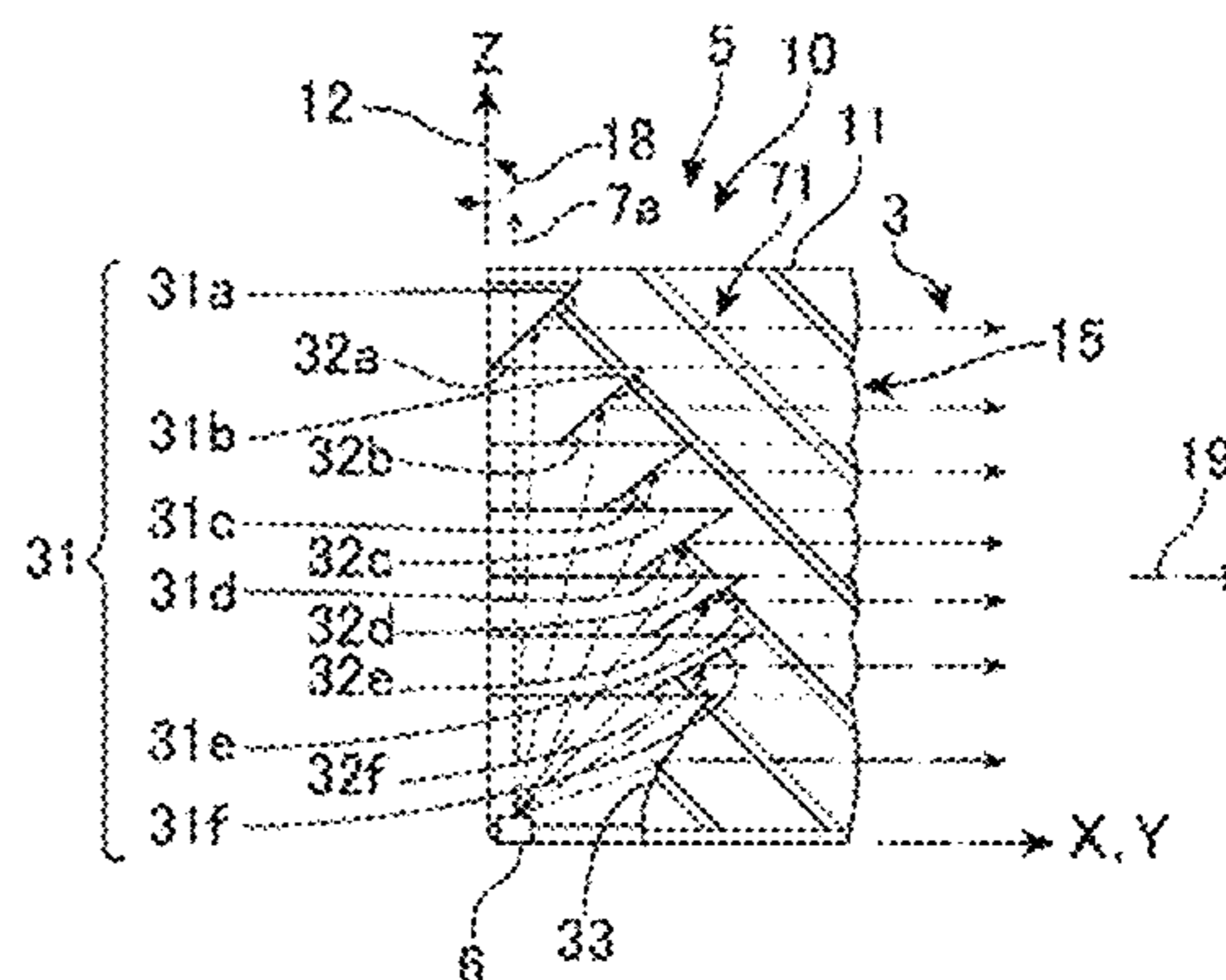
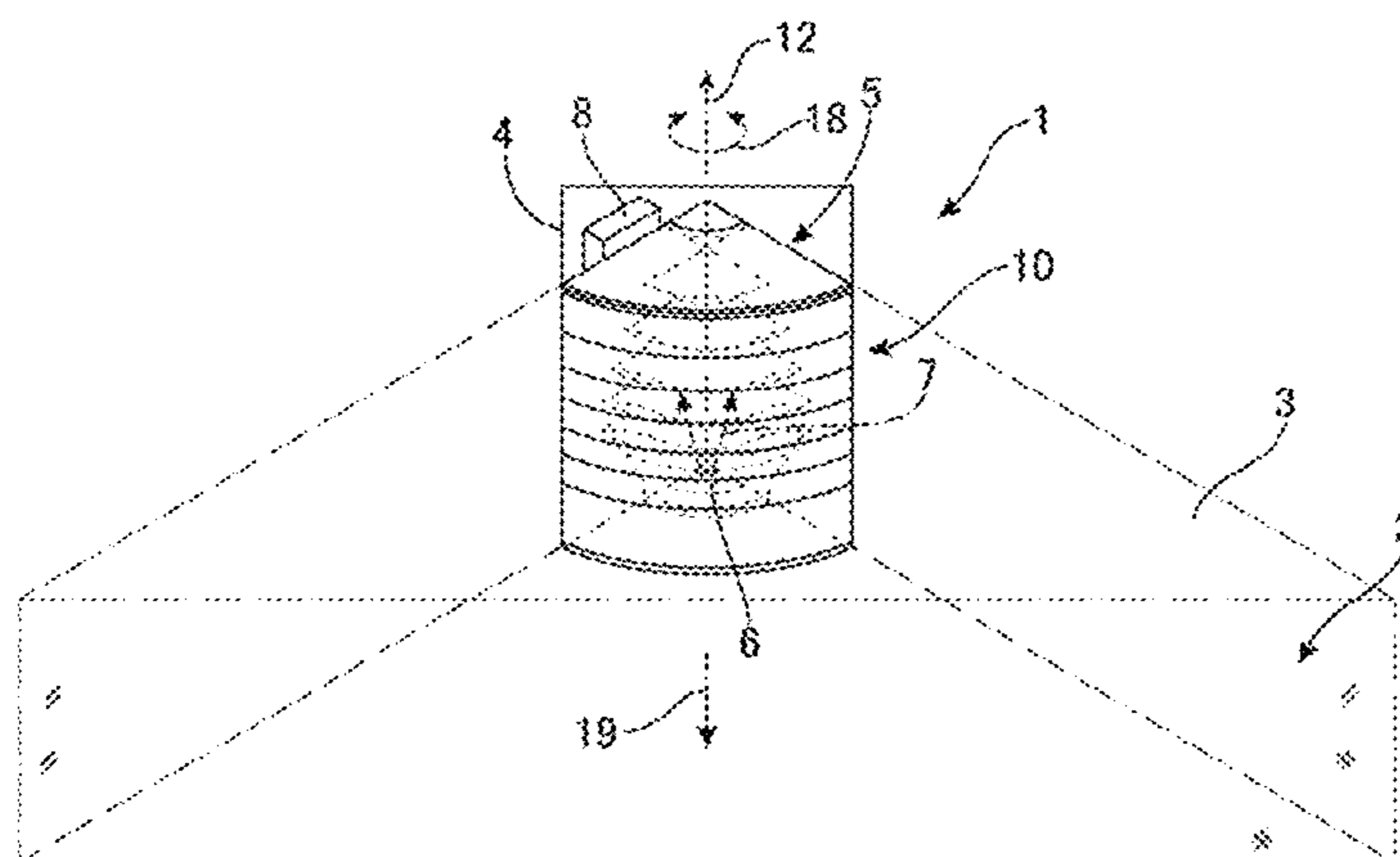


FIG. 1

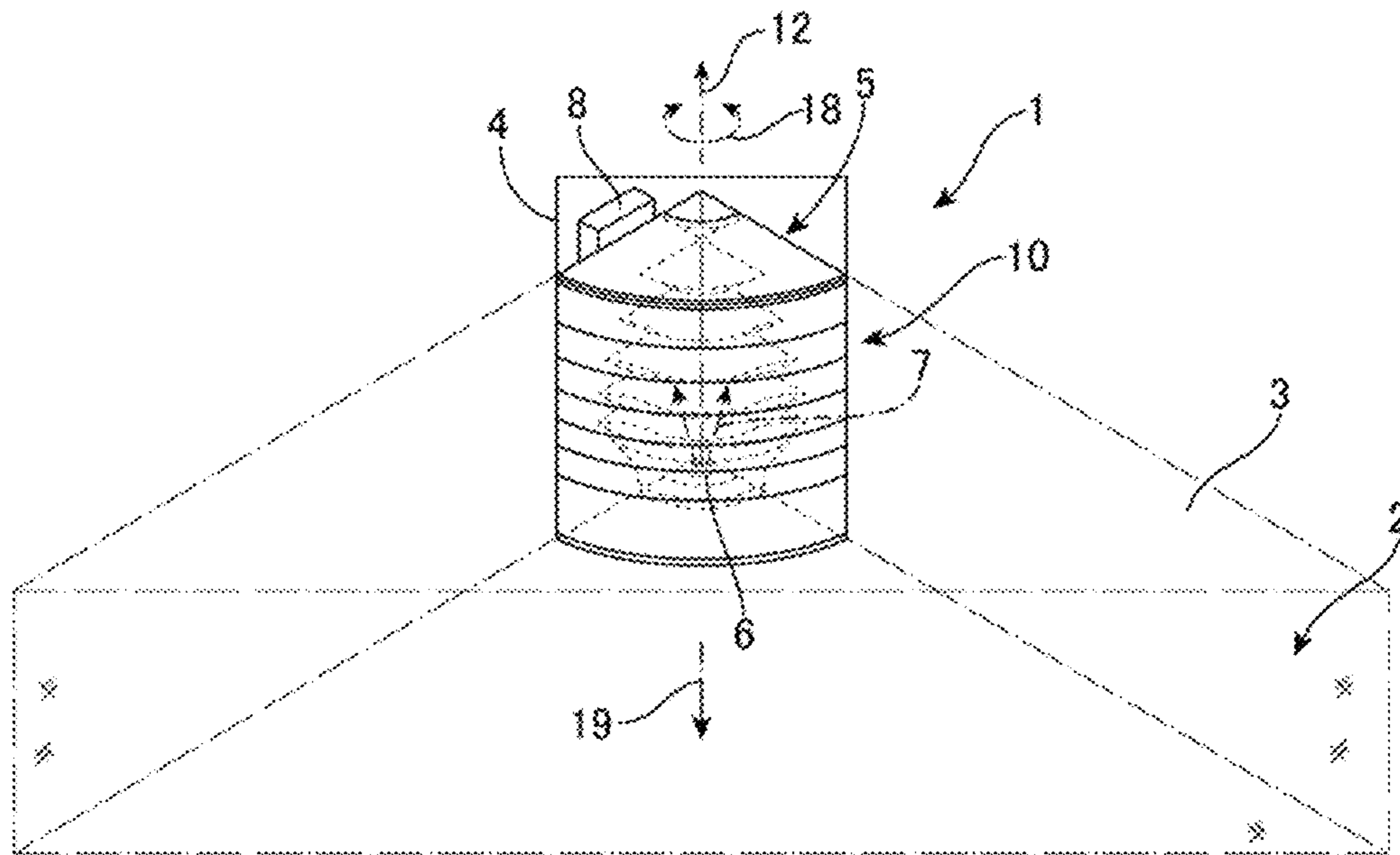


FIG. 2

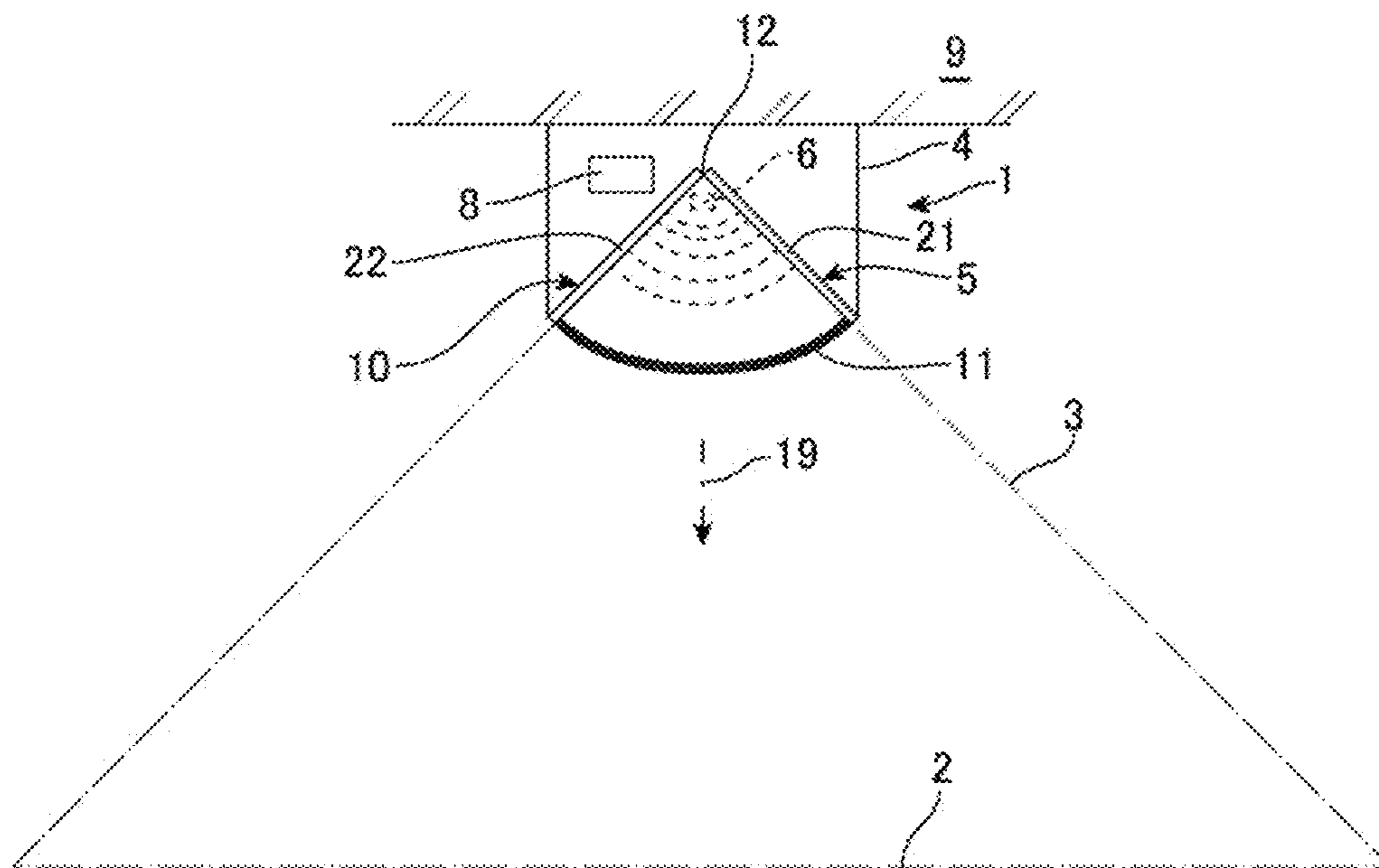


FIG. 3A

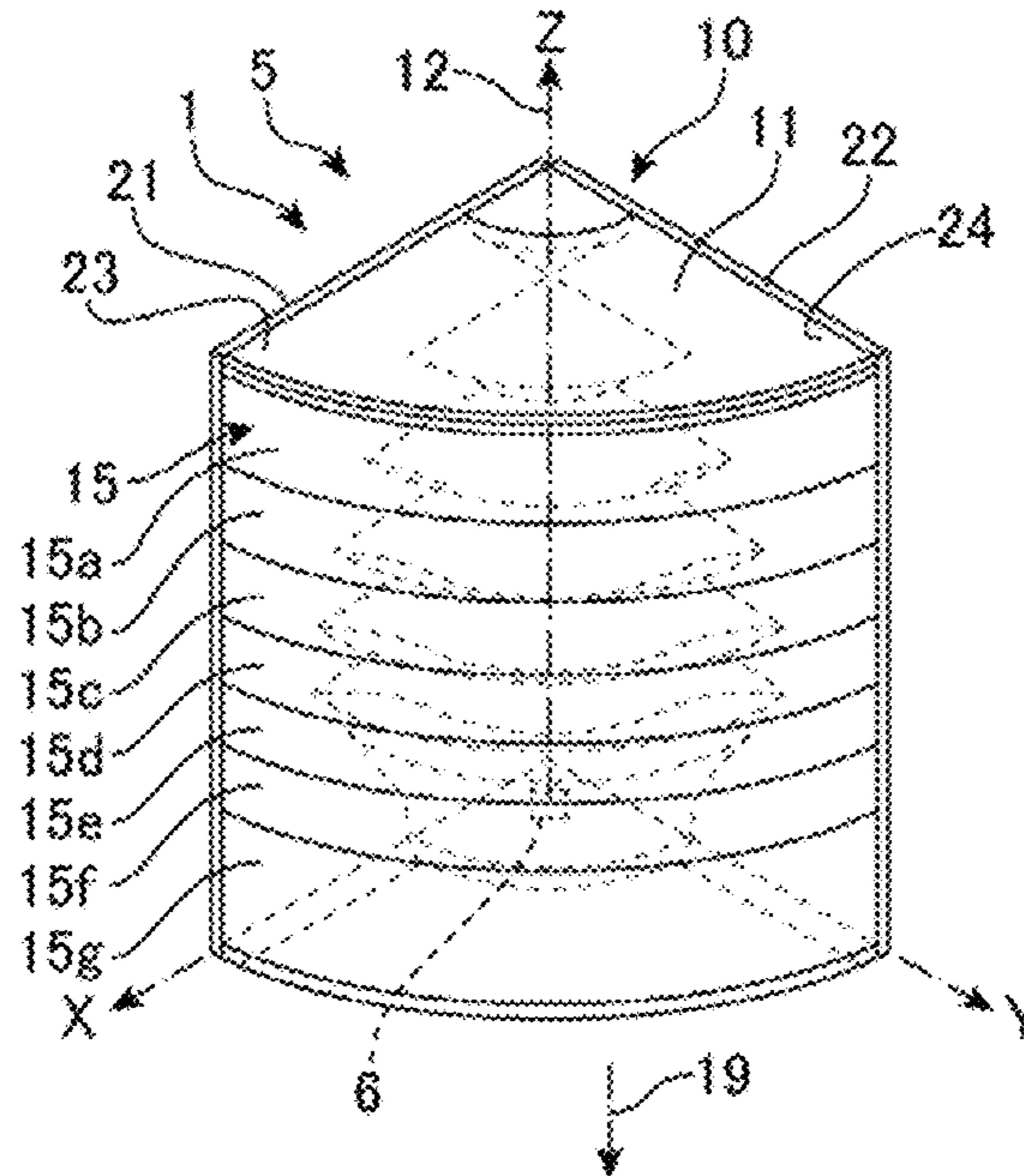


FIG. 3B

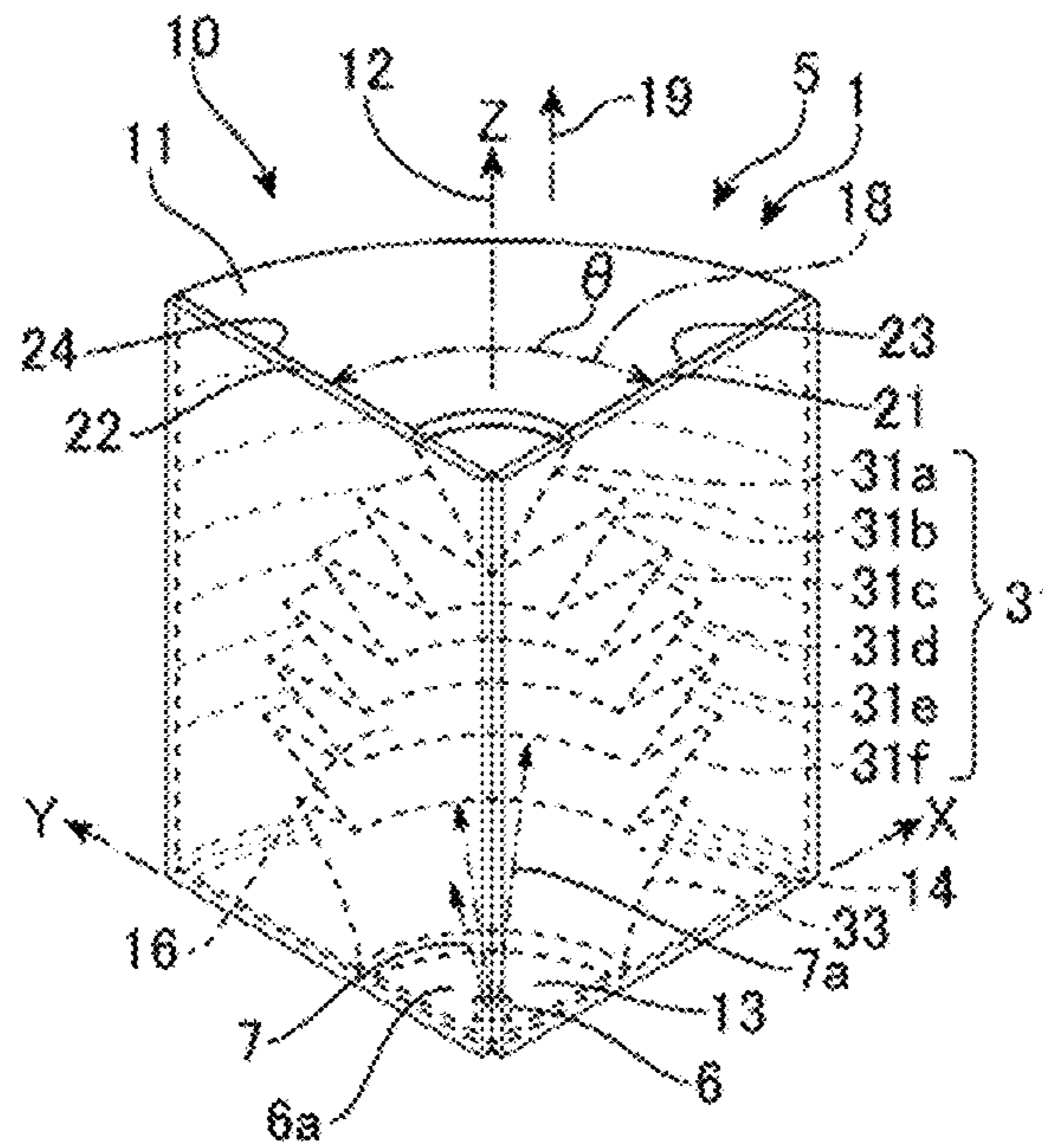


FIG. 4

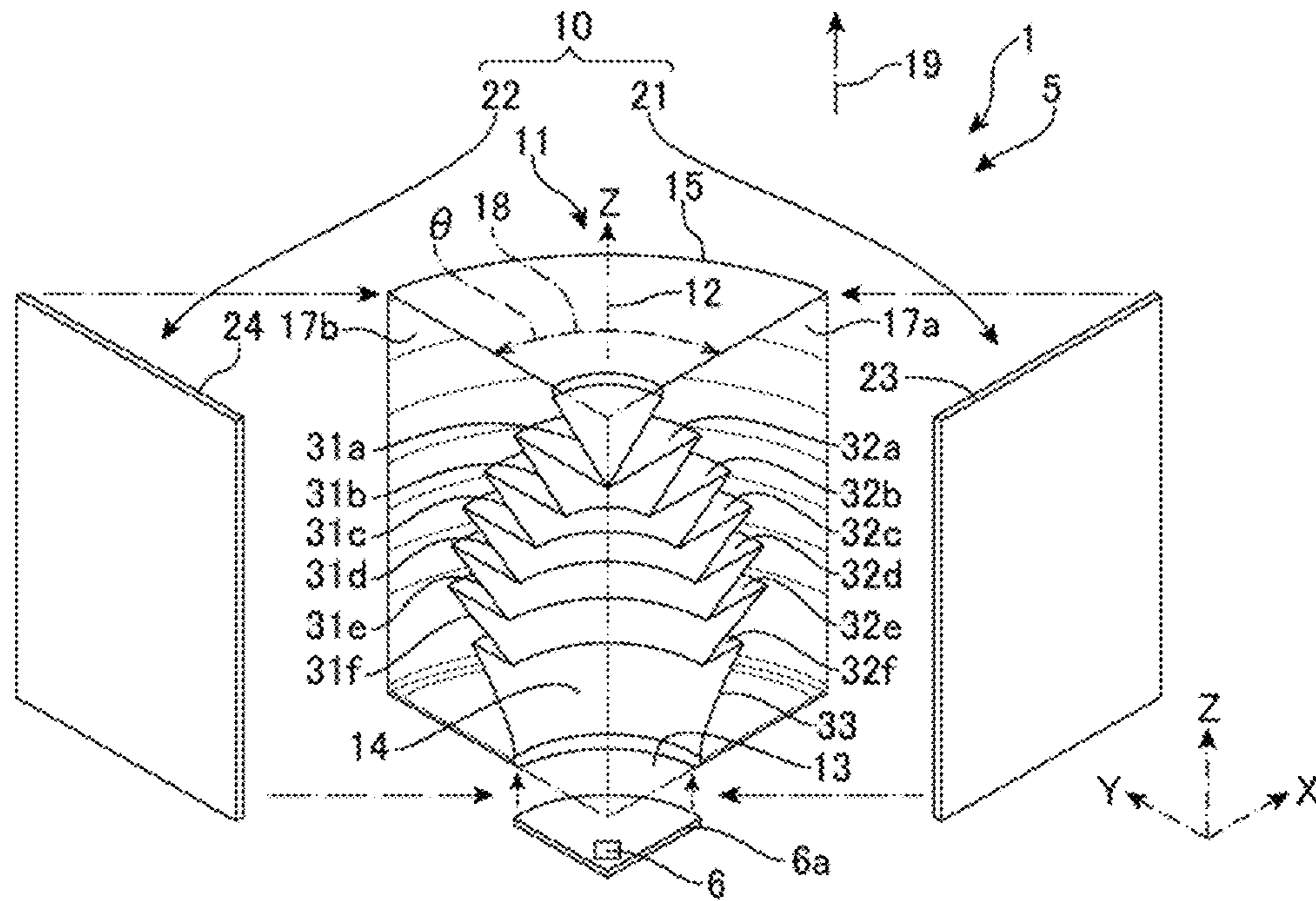


FIG. 5

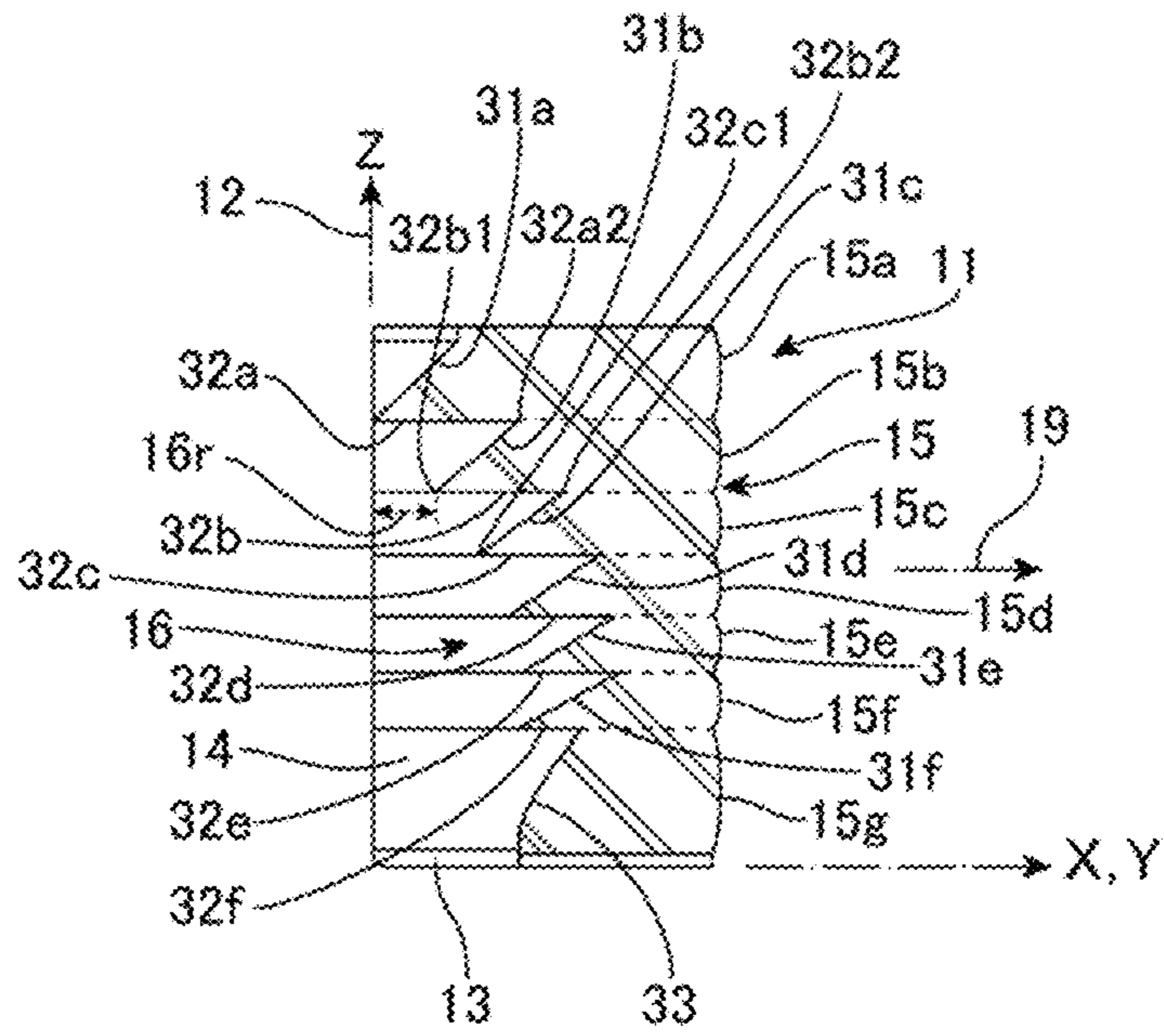


FIG. 6A

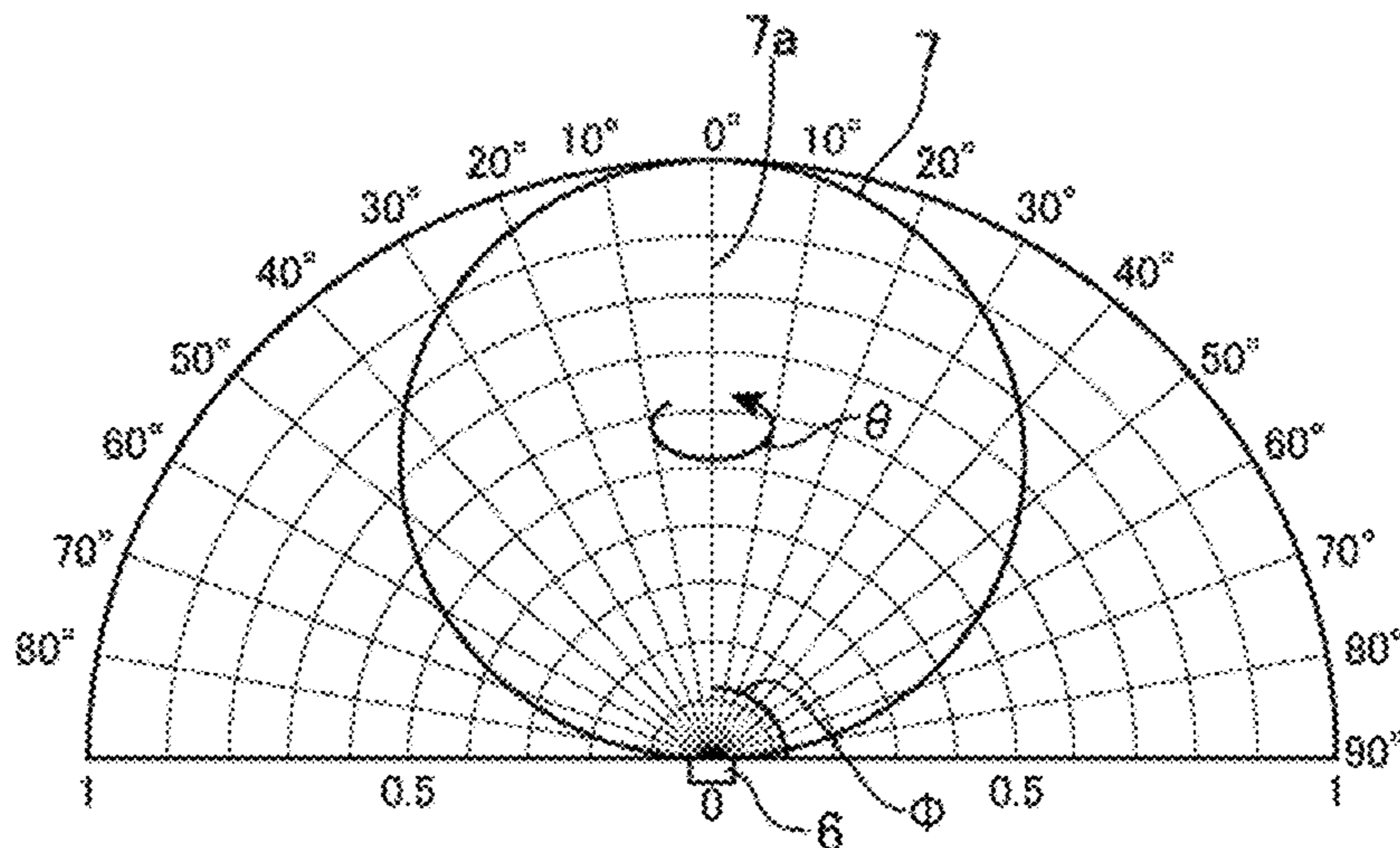


FIG. 6B

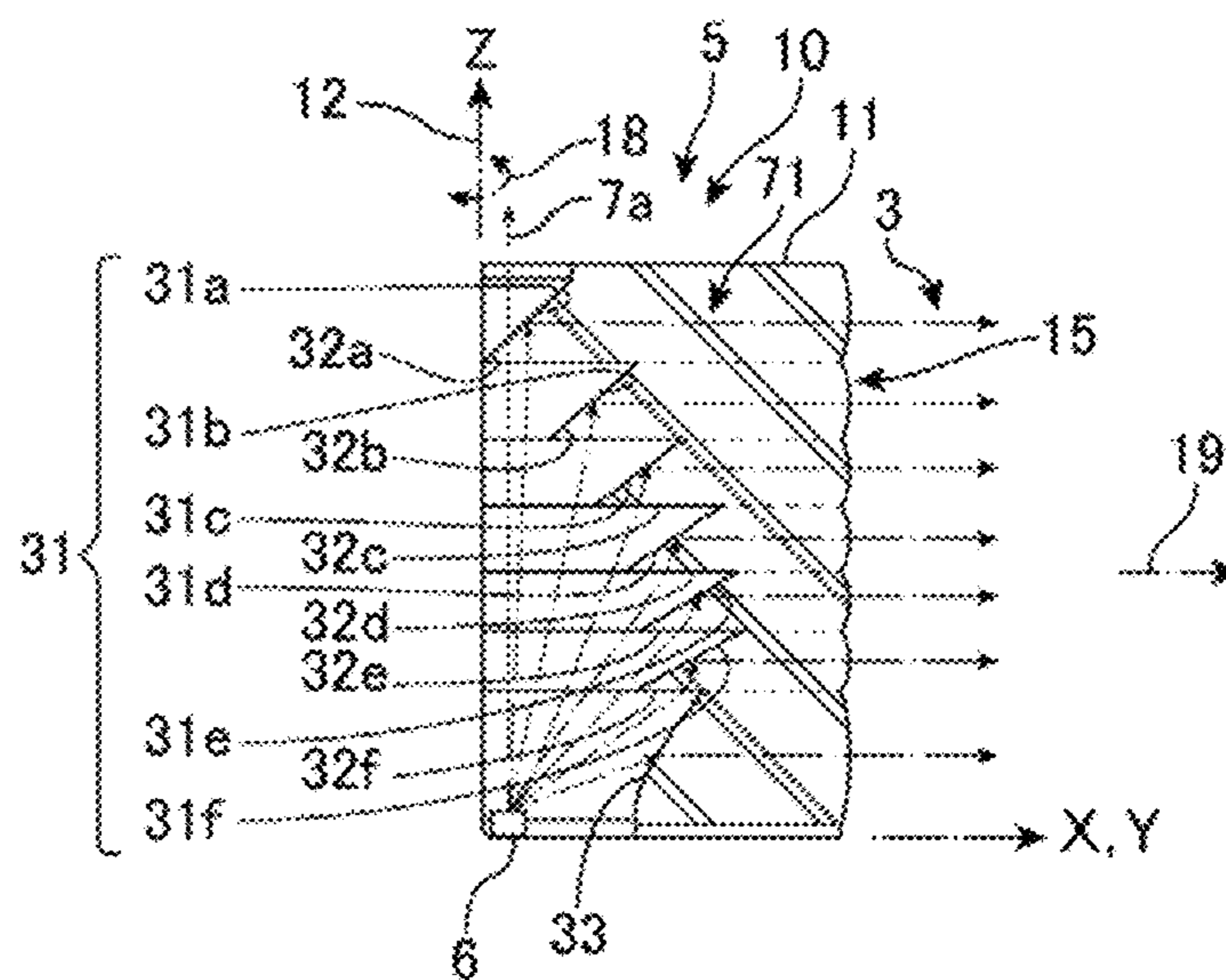


FIG. 7A

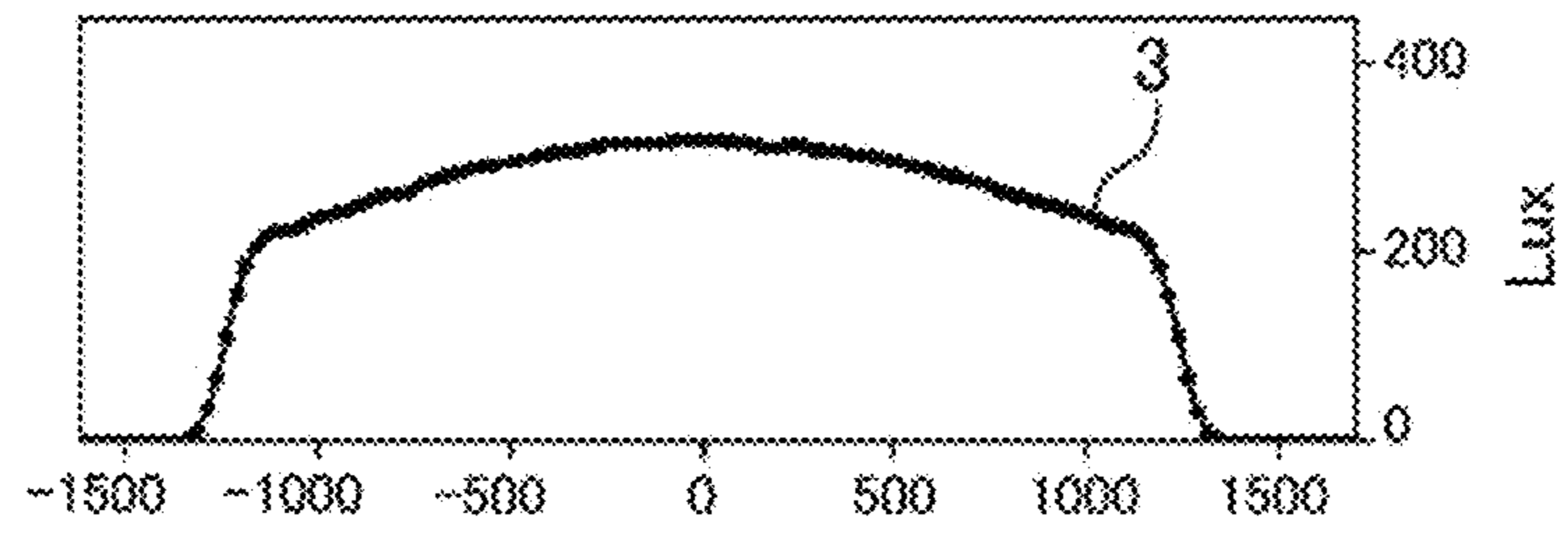


FIG. 7B

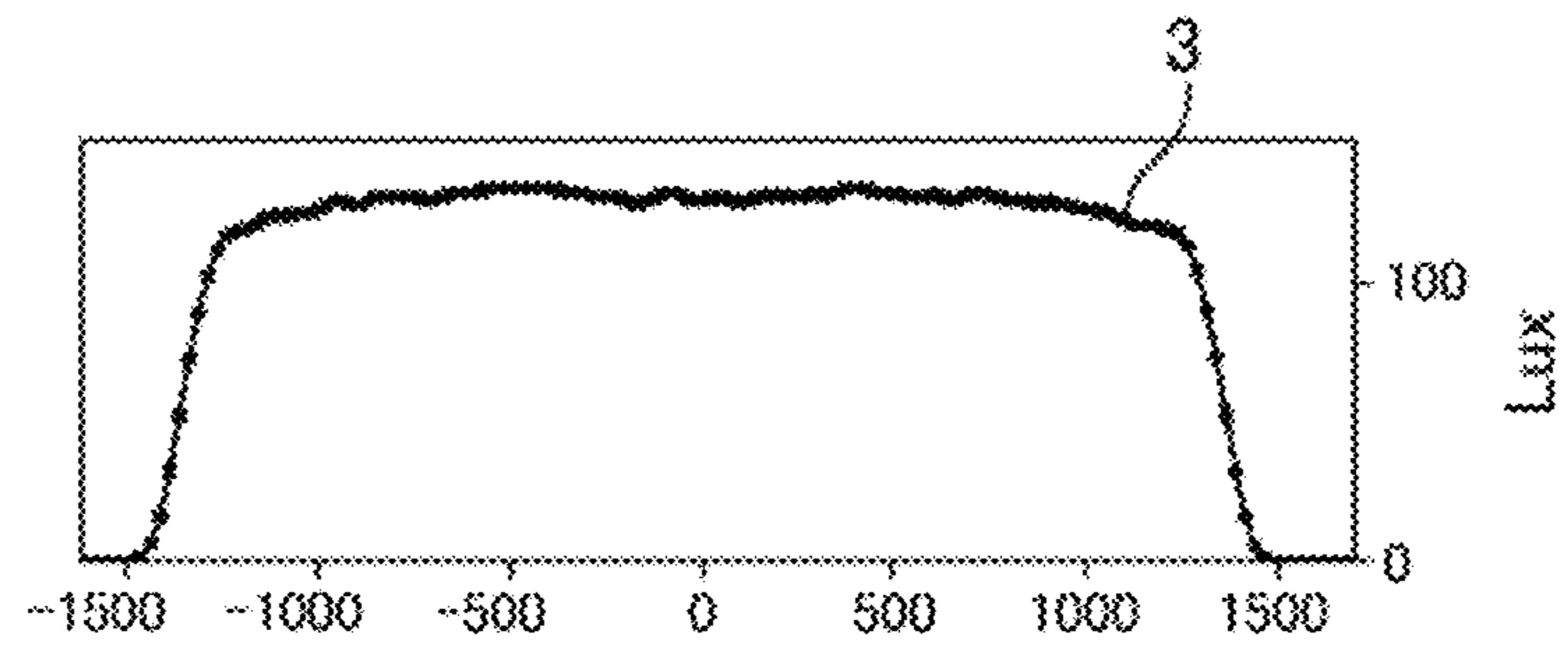


FIG. 8

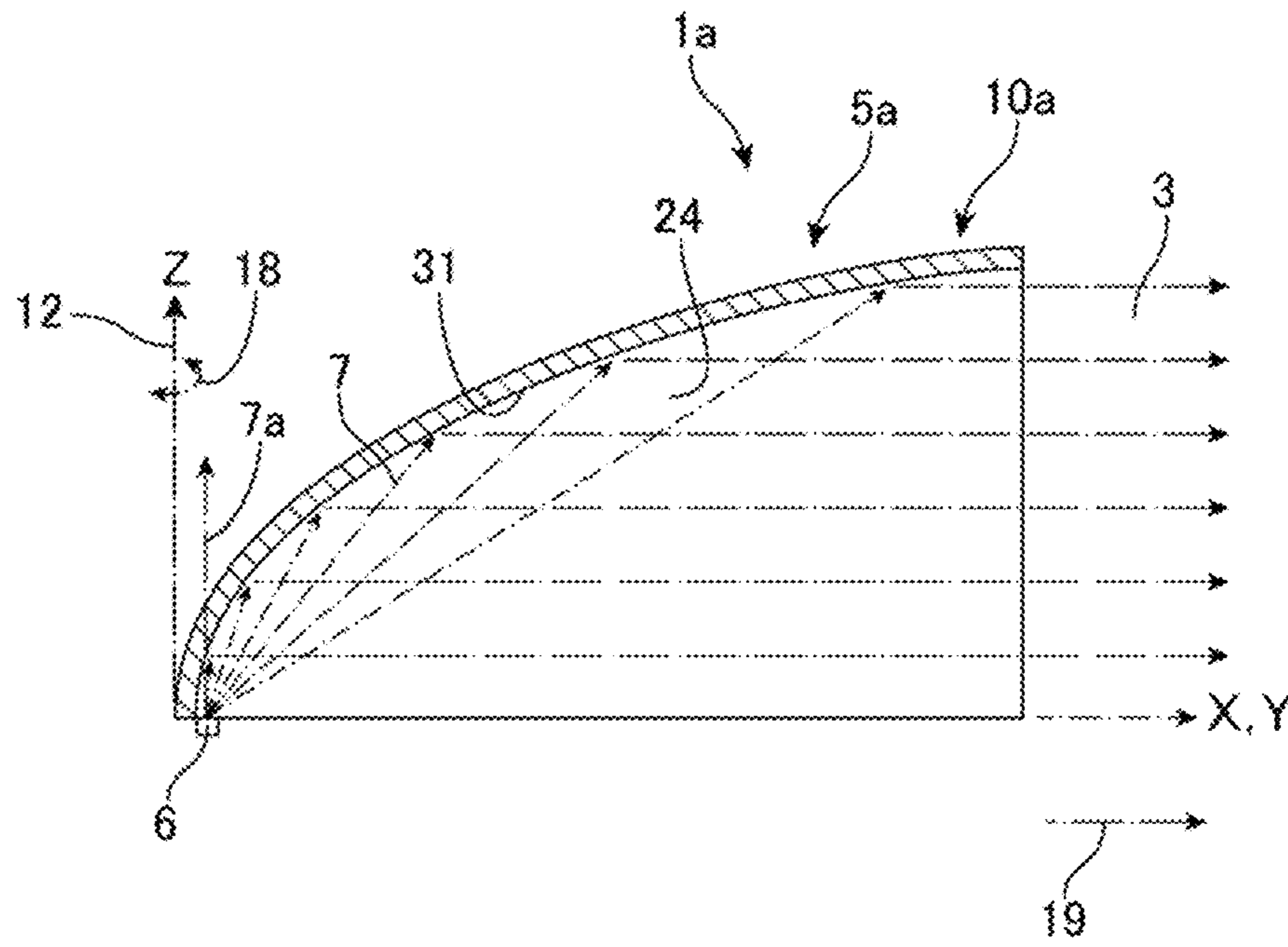


FIG. 9A

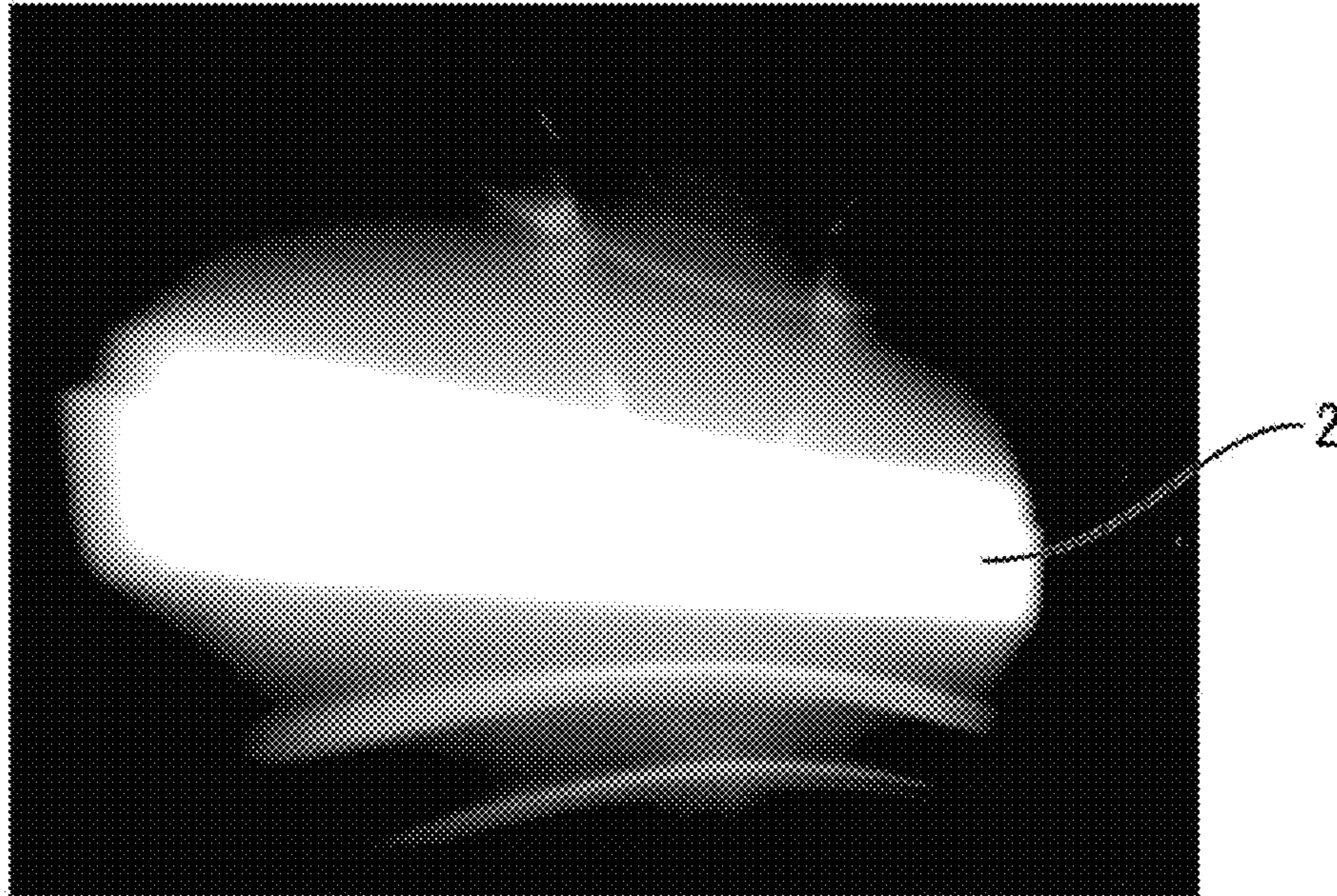


FIG. 9B

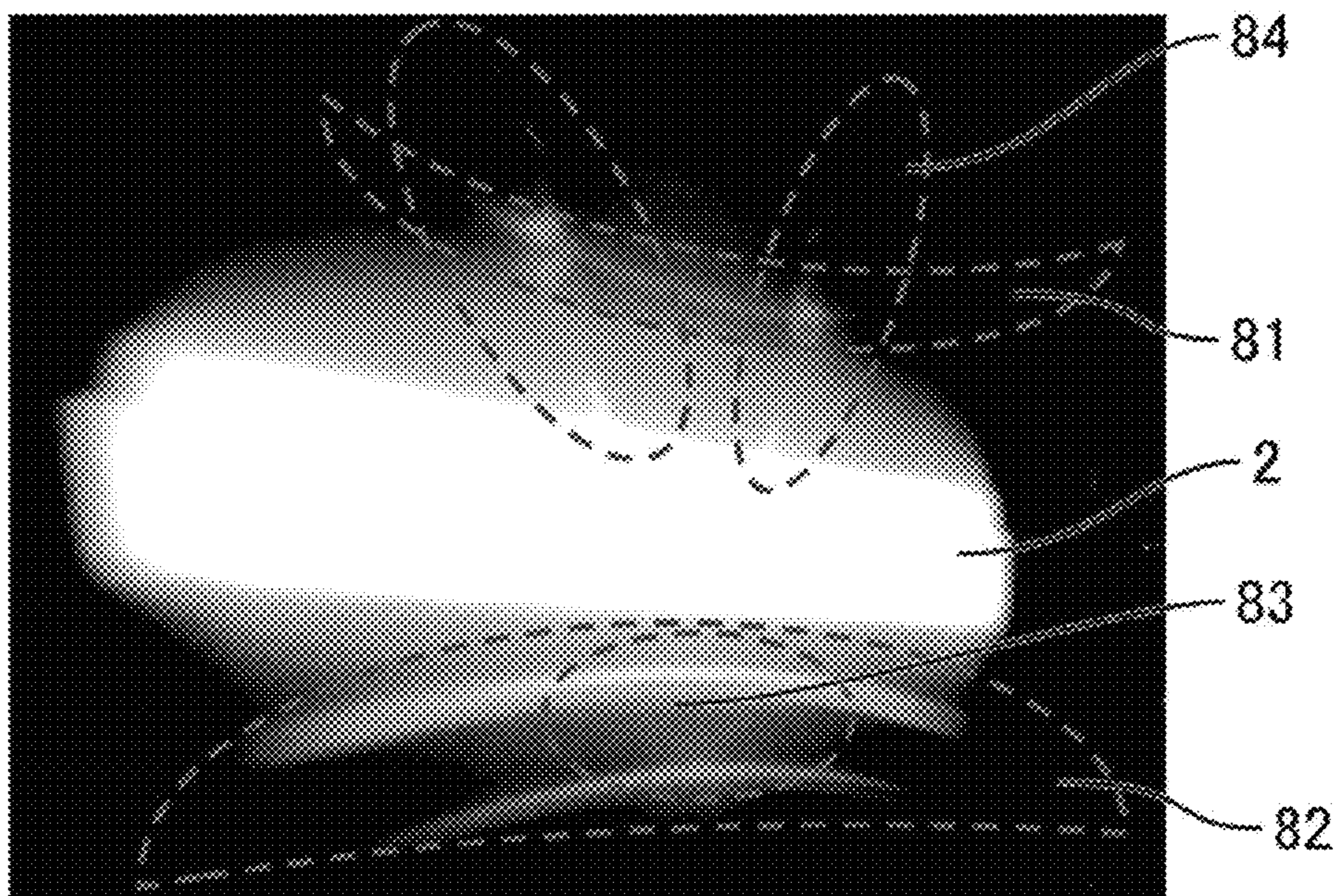


FIG. 10

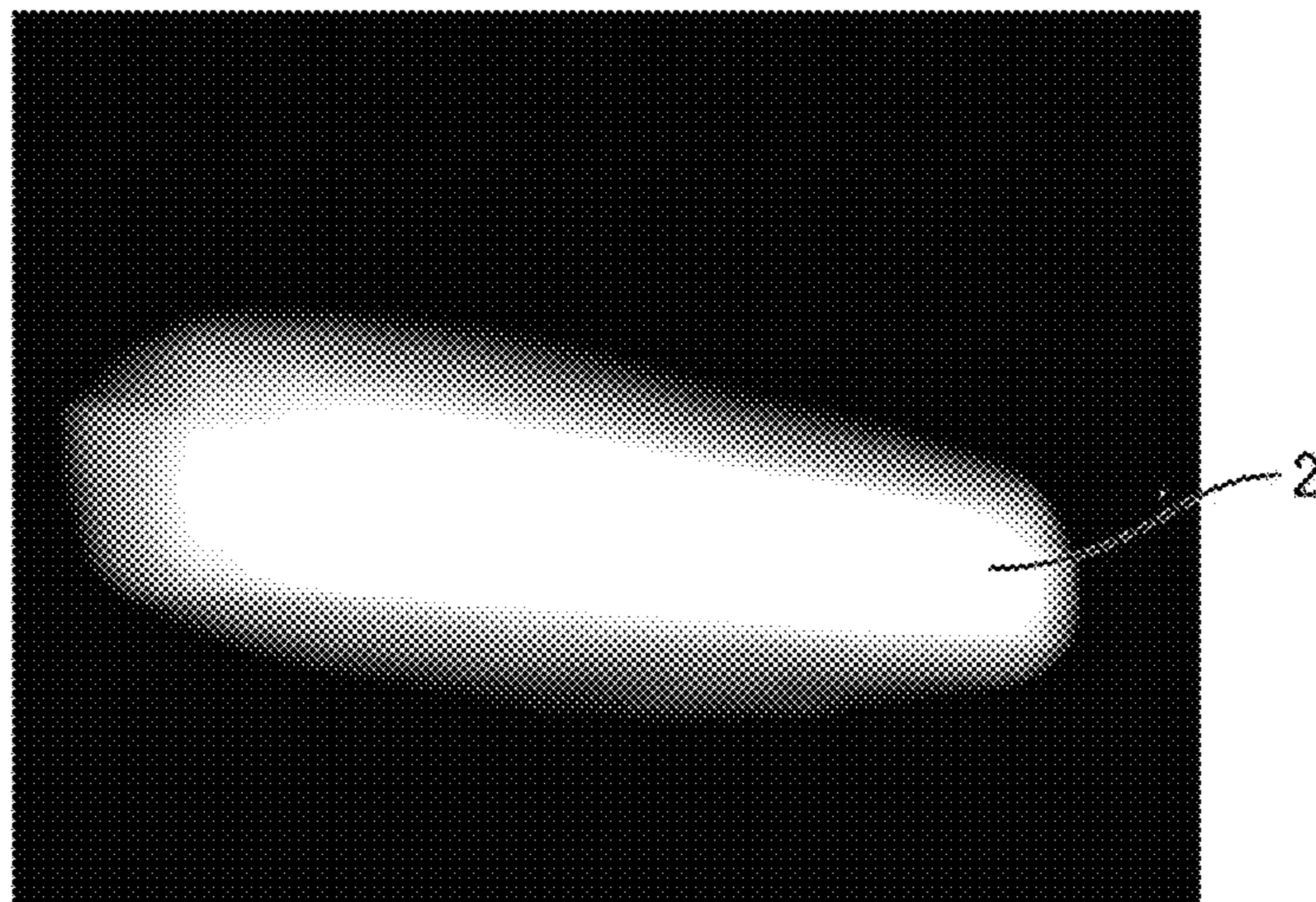


FIG. 11A

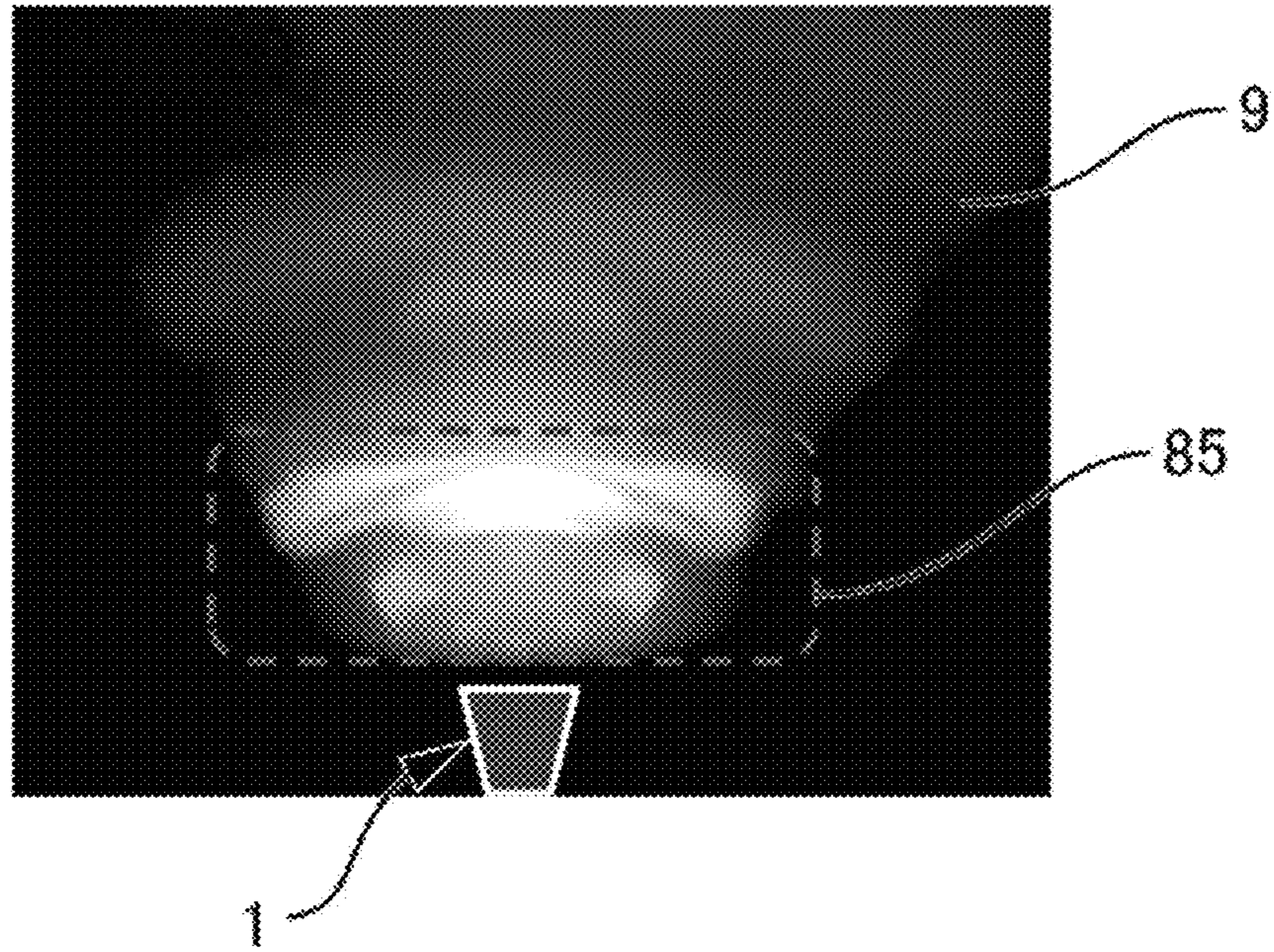


FIG. 11B

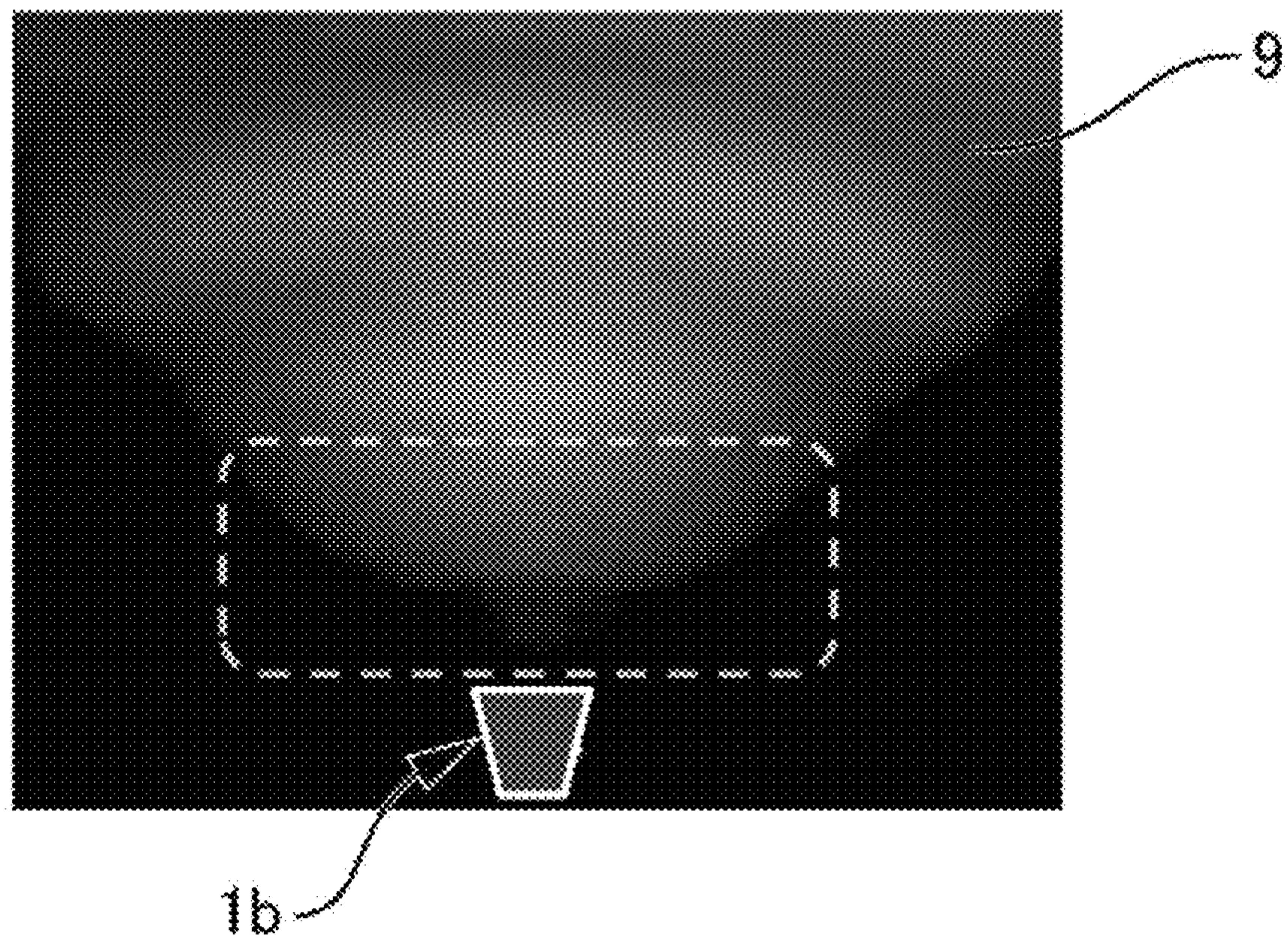


FIG. 13A

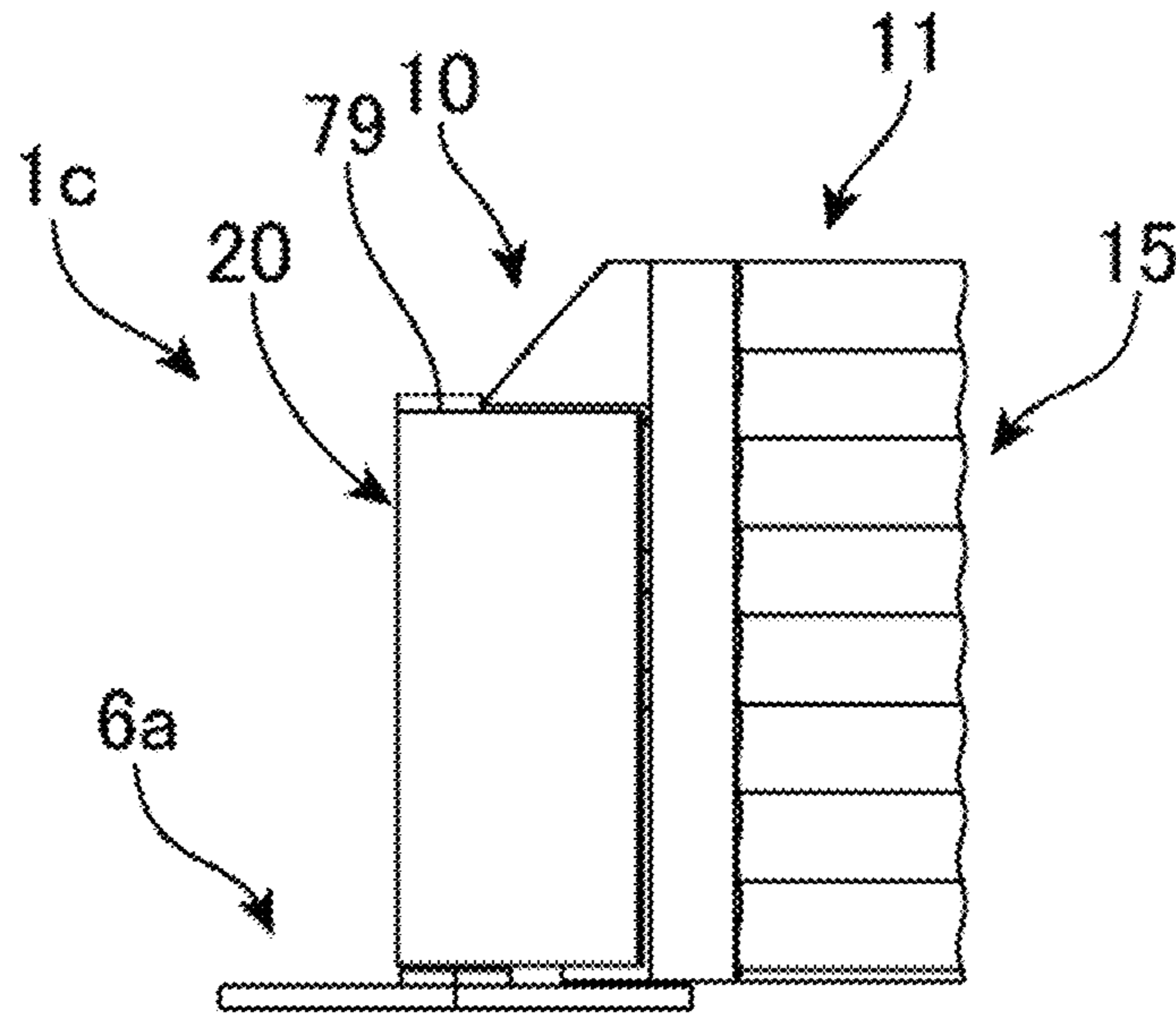


FIG. 13B

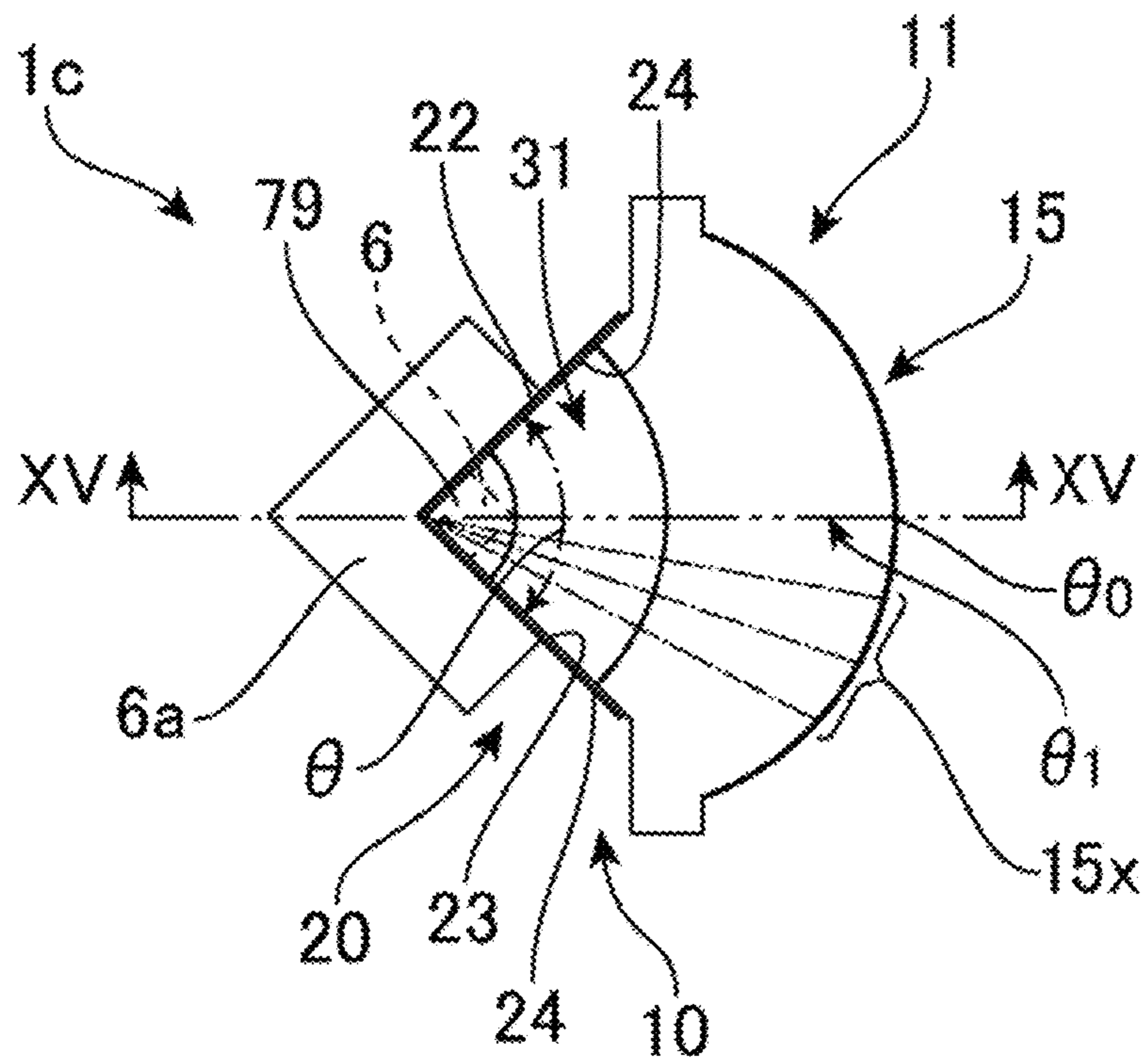


FIG. 14

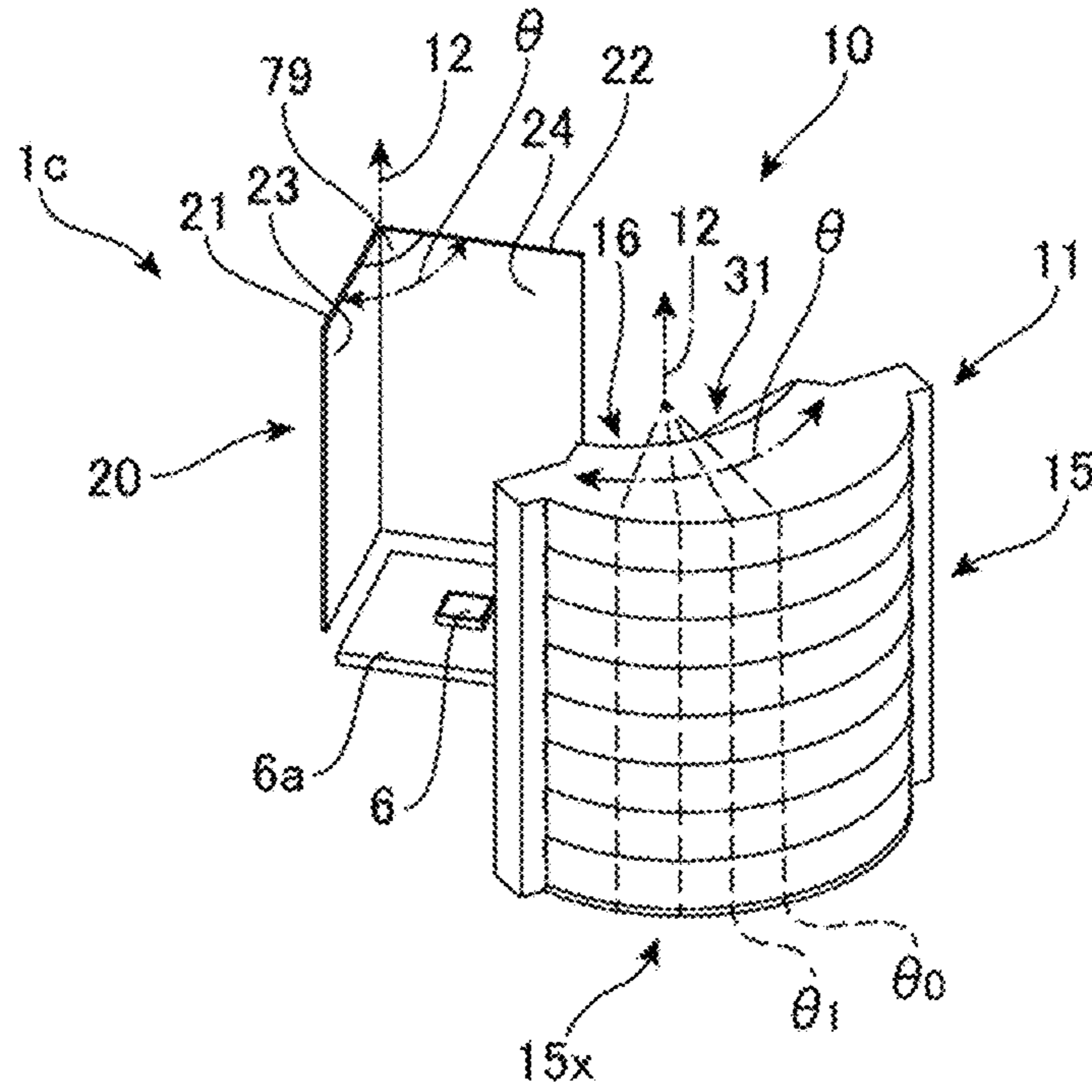


FIG. 15

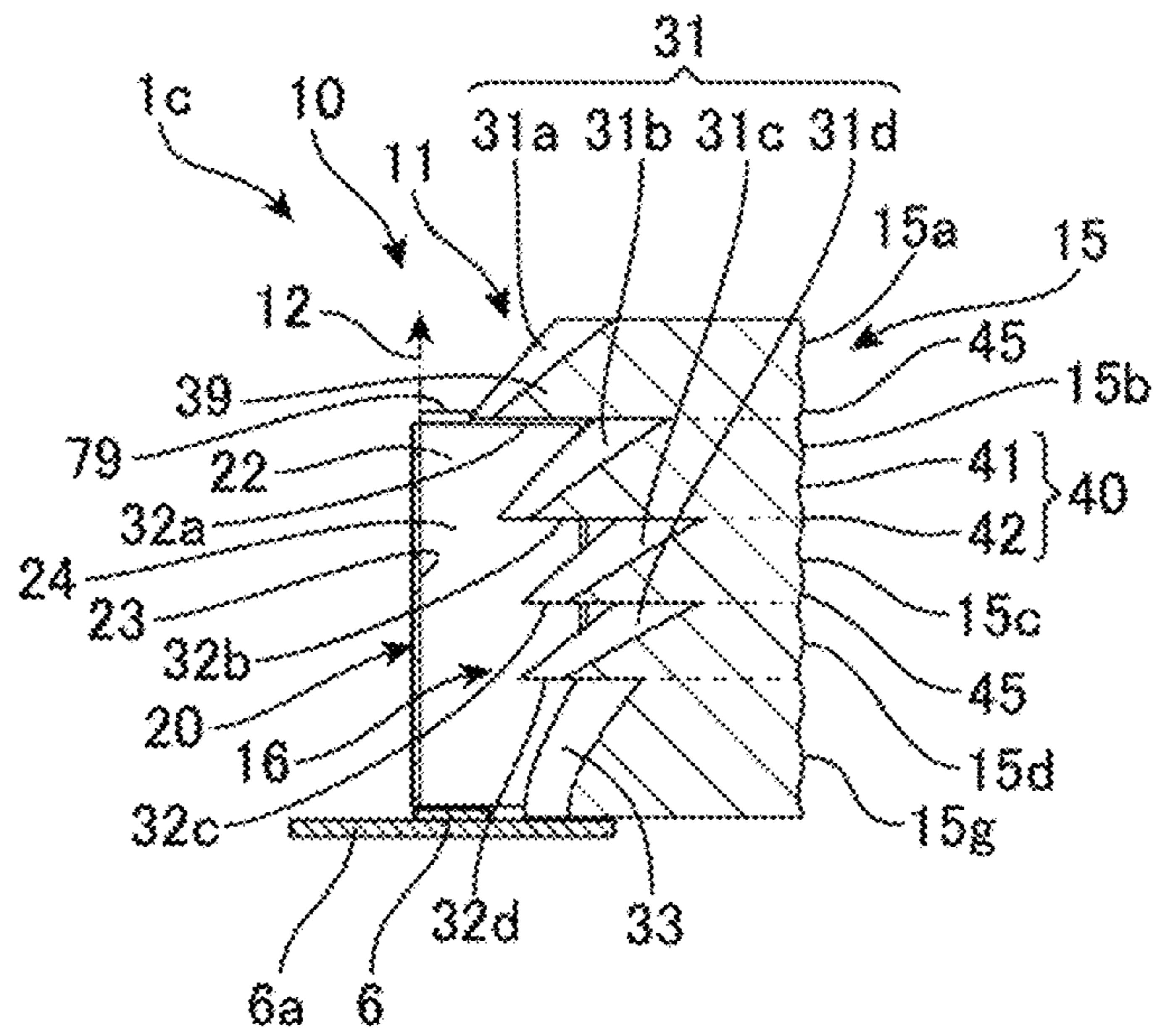


FIG. 16

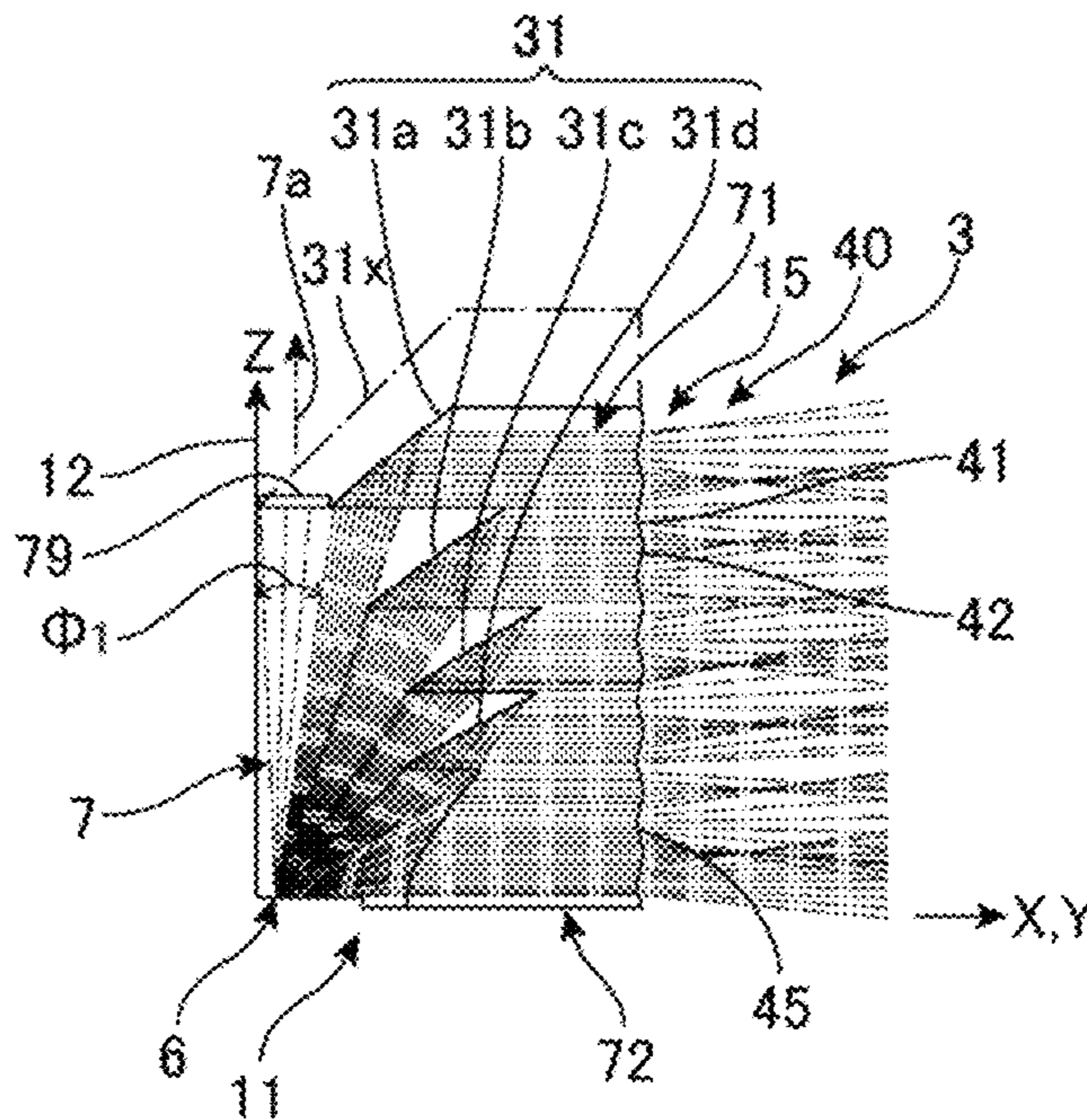


FIG. 17

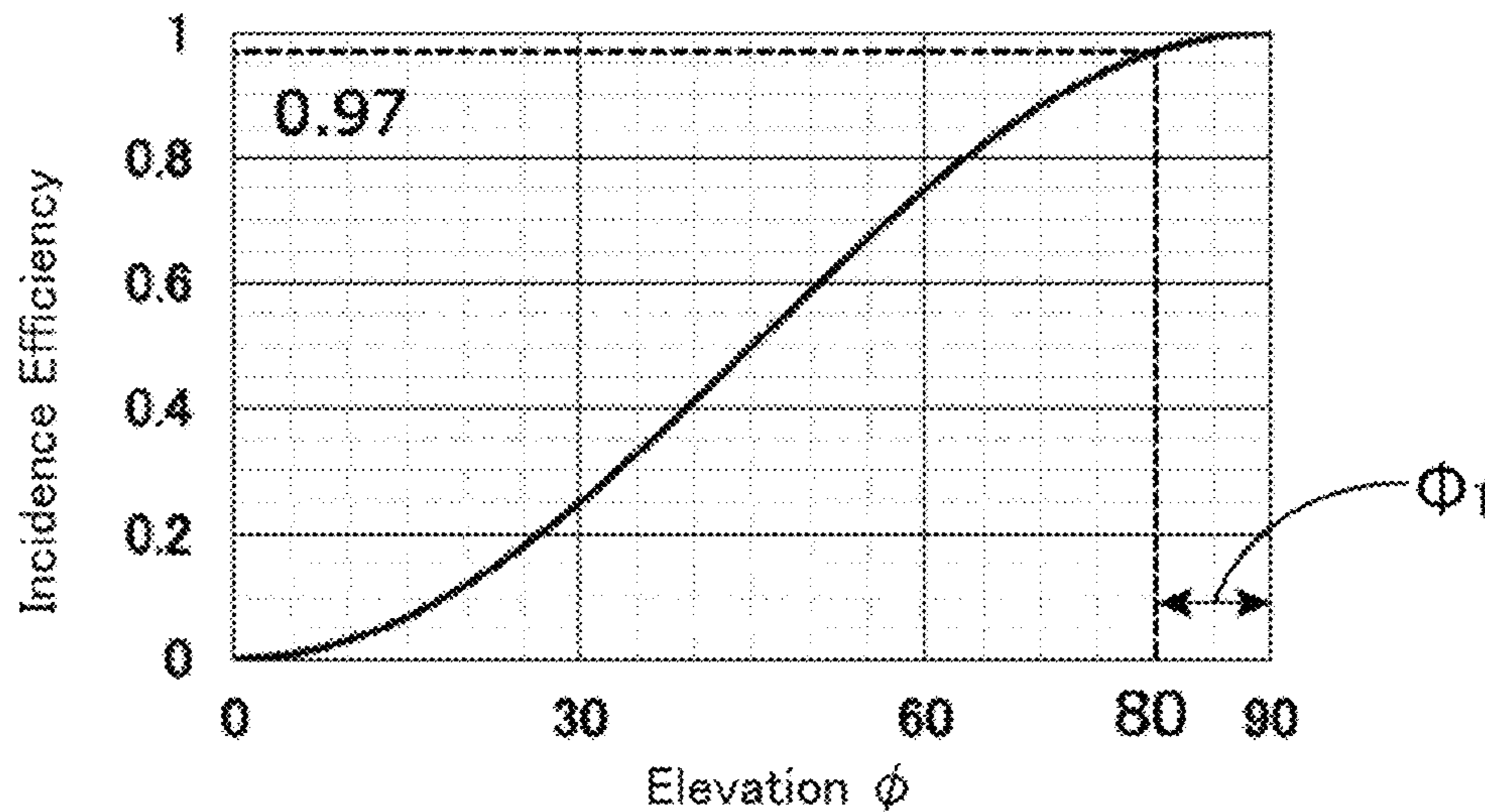


FIG. 18A

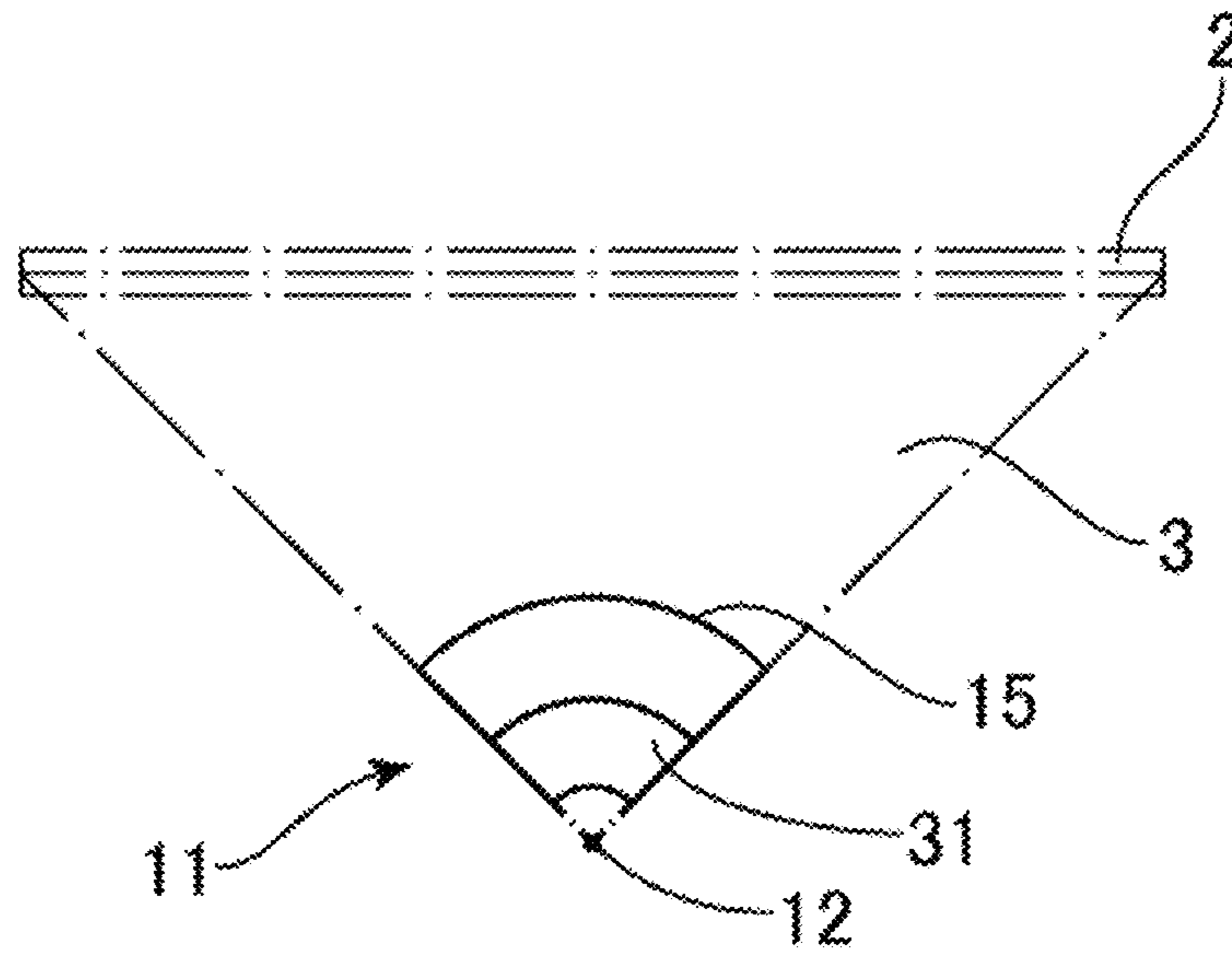


FIG. 18B

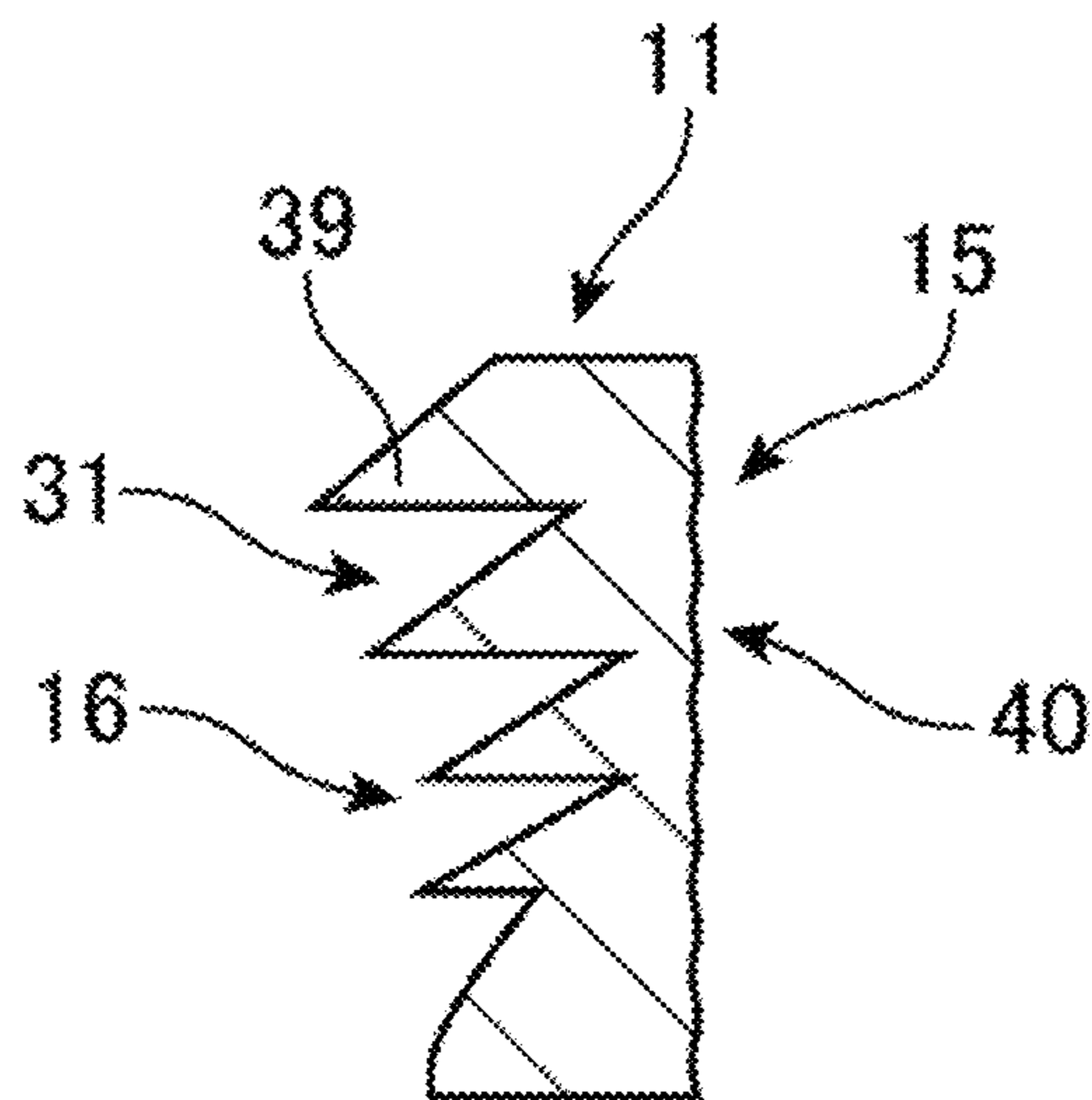


FIG. 19A

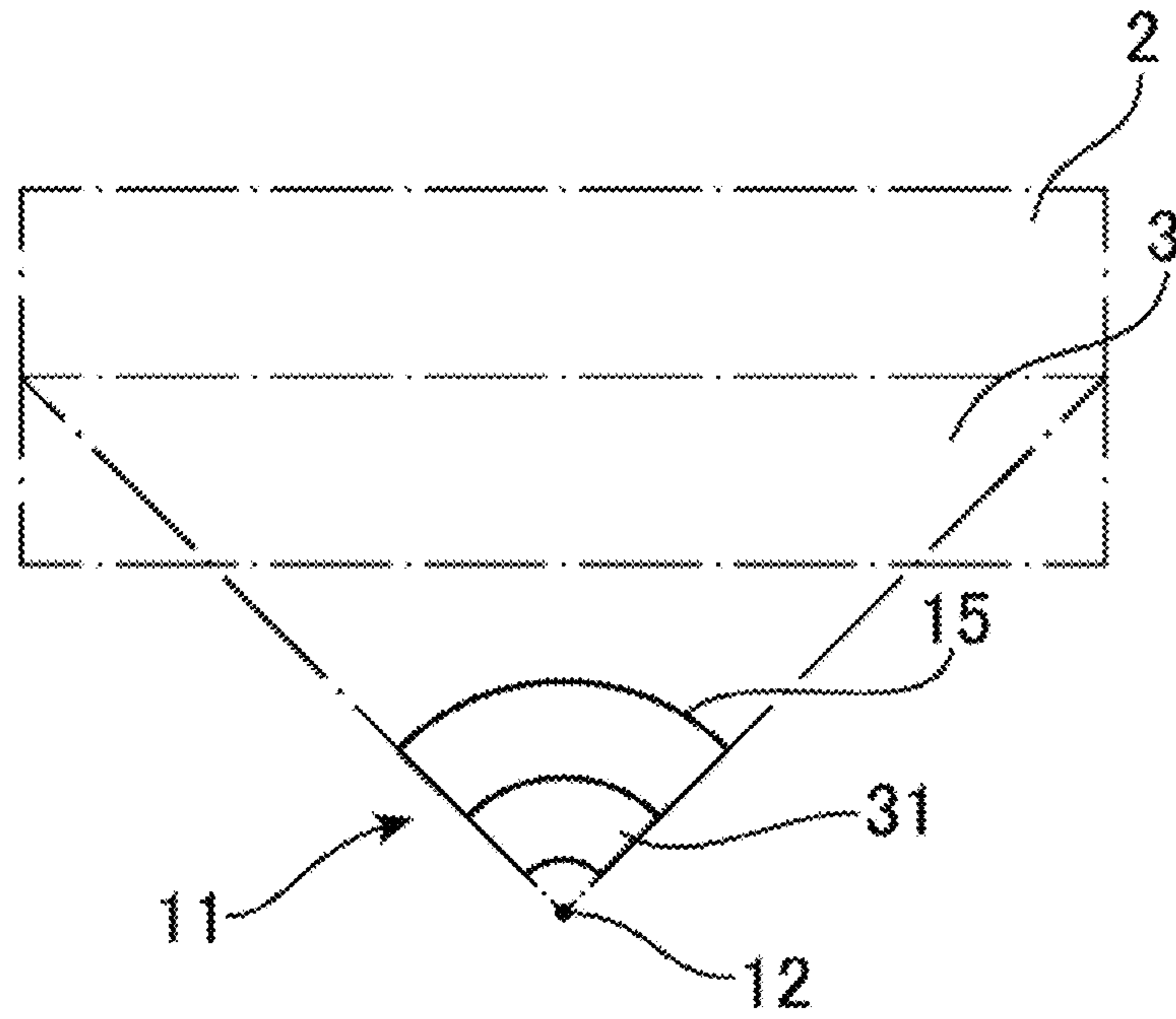


FIG. 19B

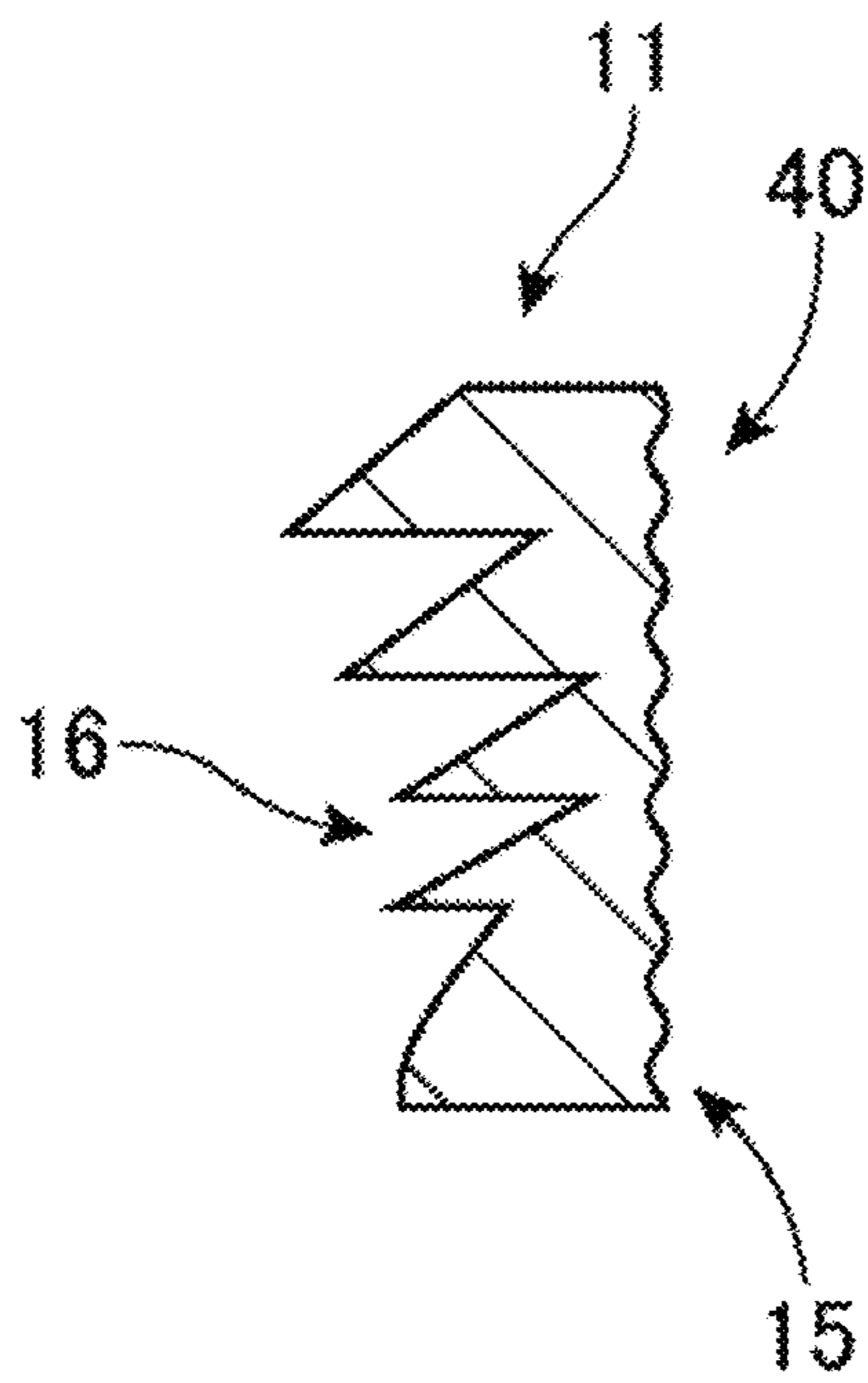


FIG. 19C

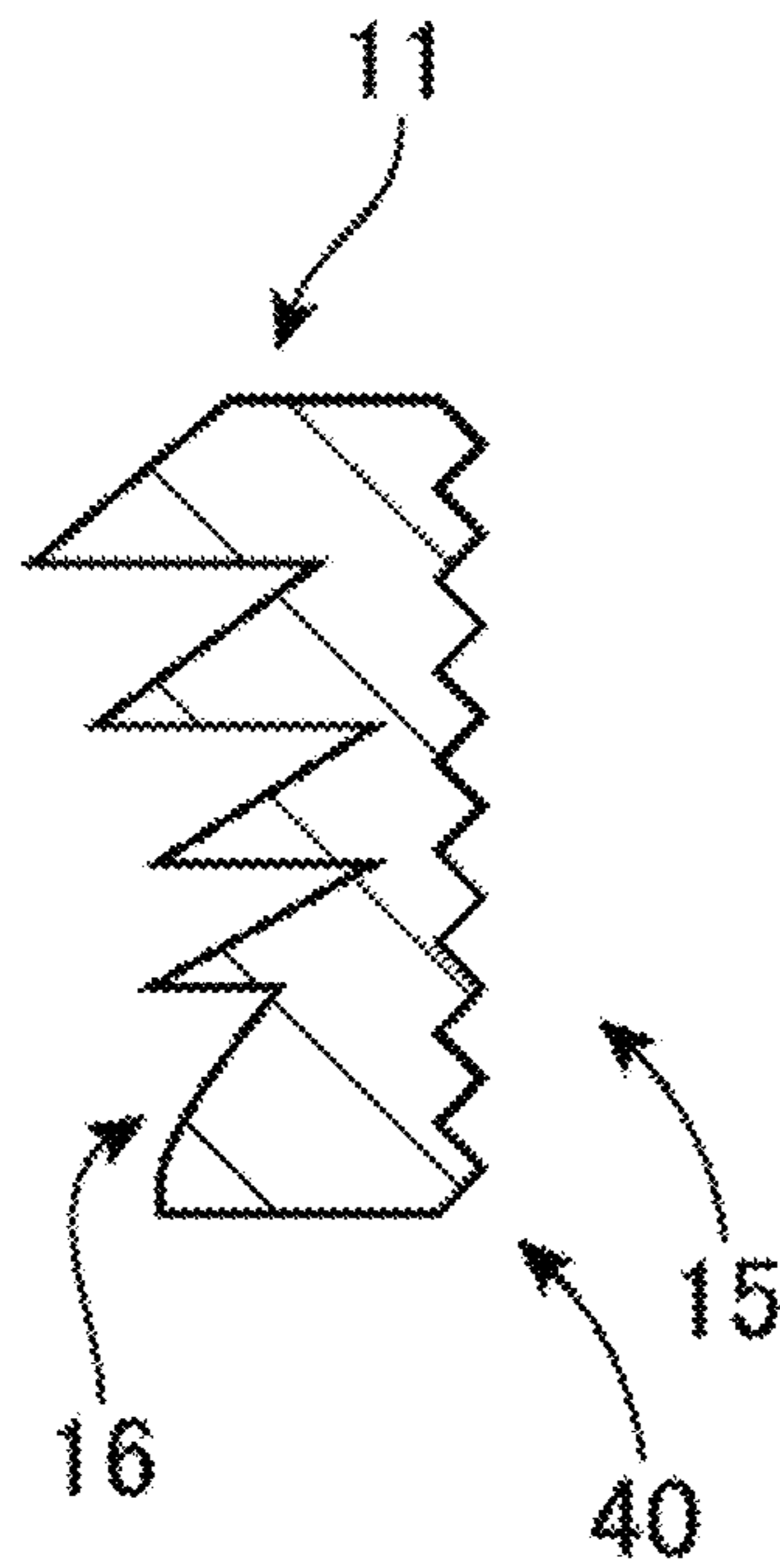


FIG. 20A

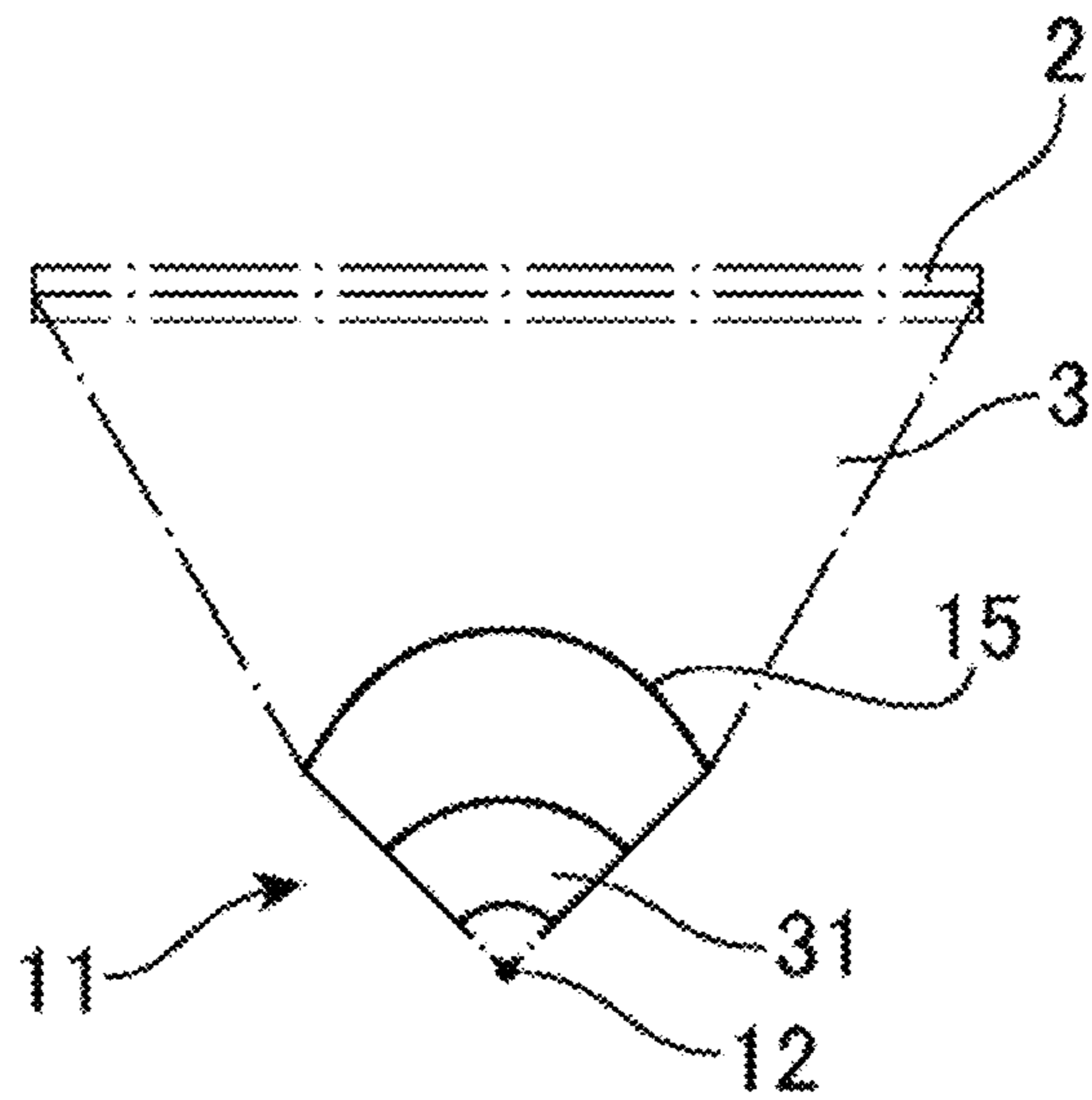


FIG. 20B

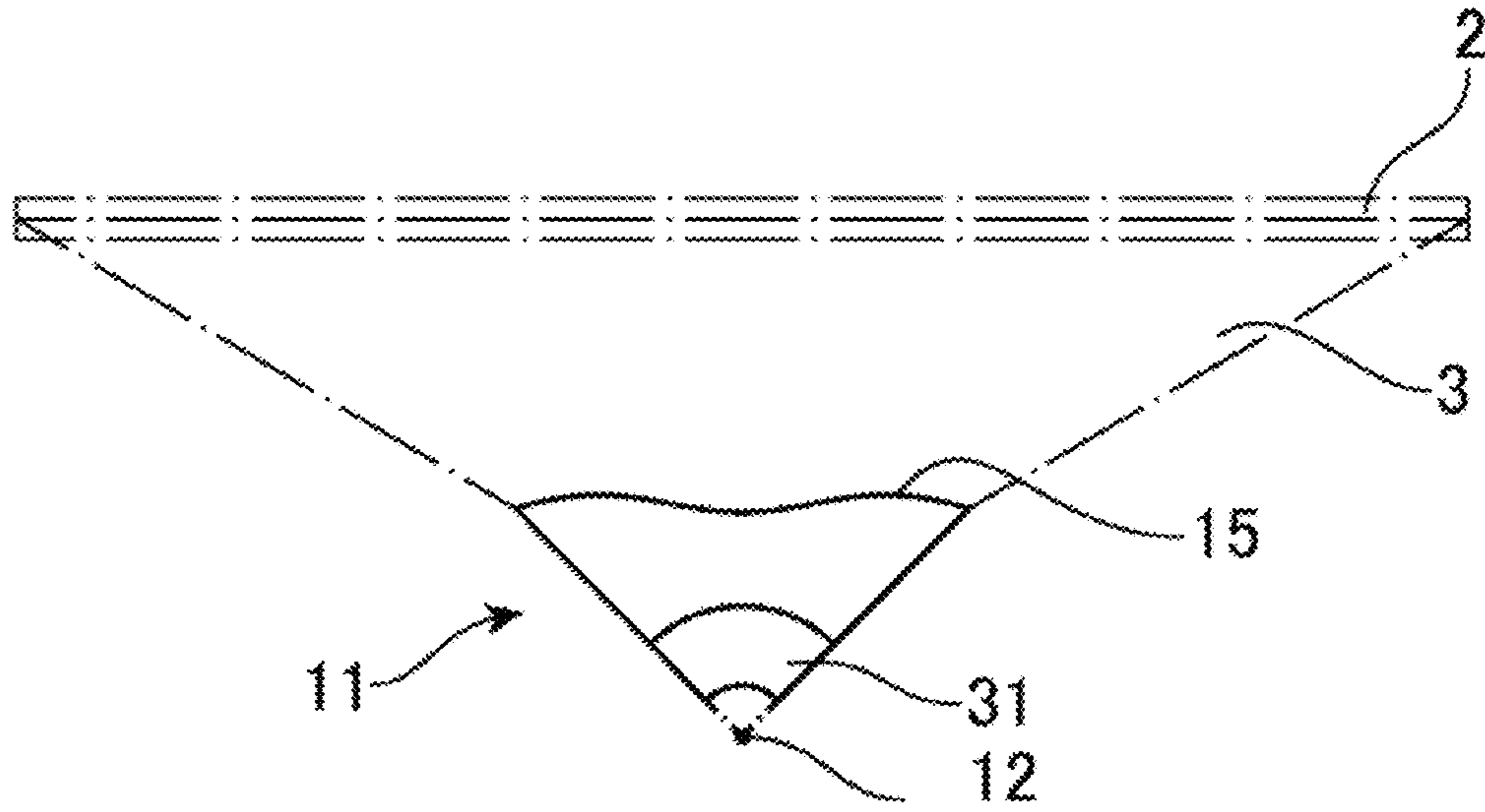


FIG. 20C

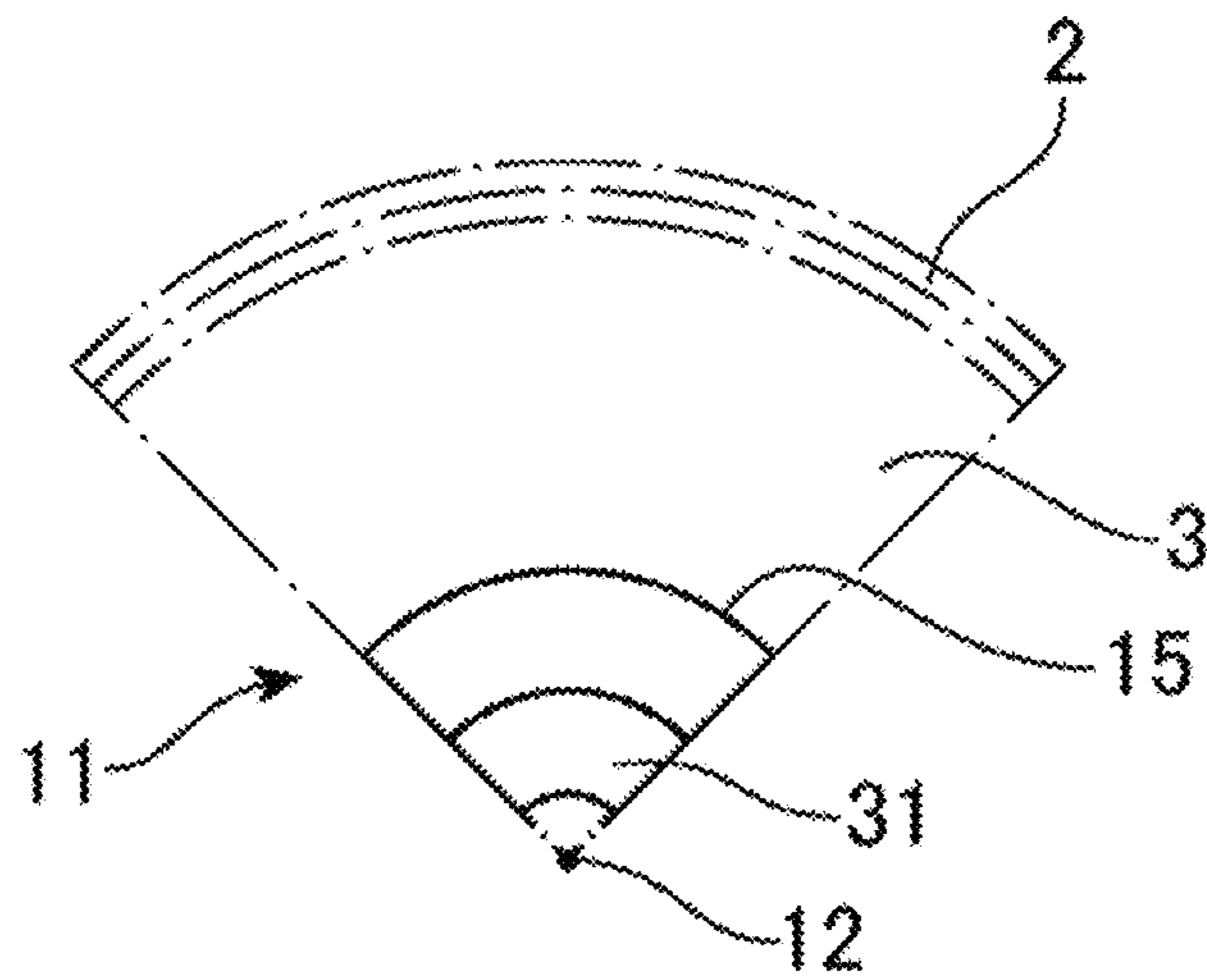


FIG. 21A

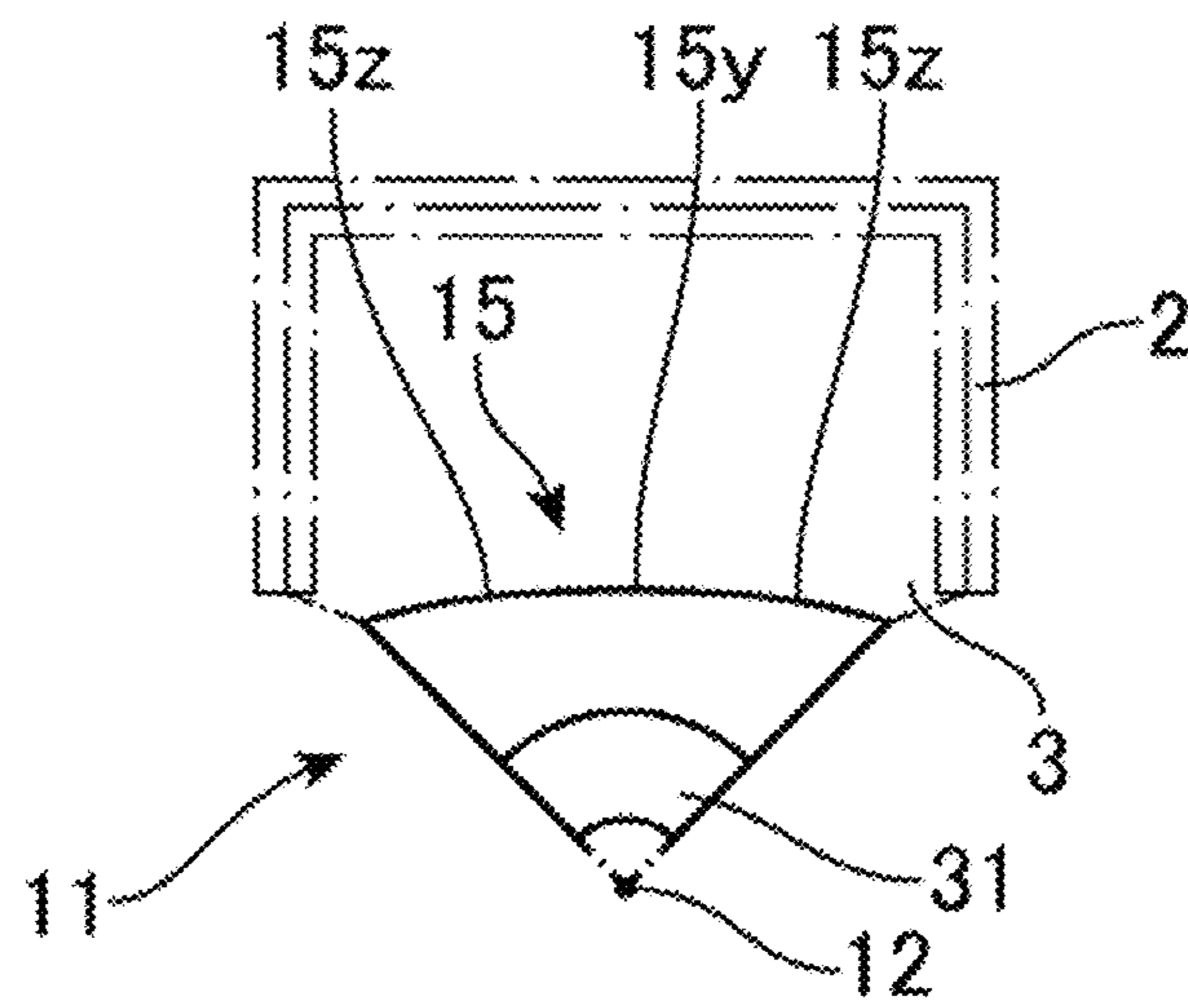


FIG. 21B

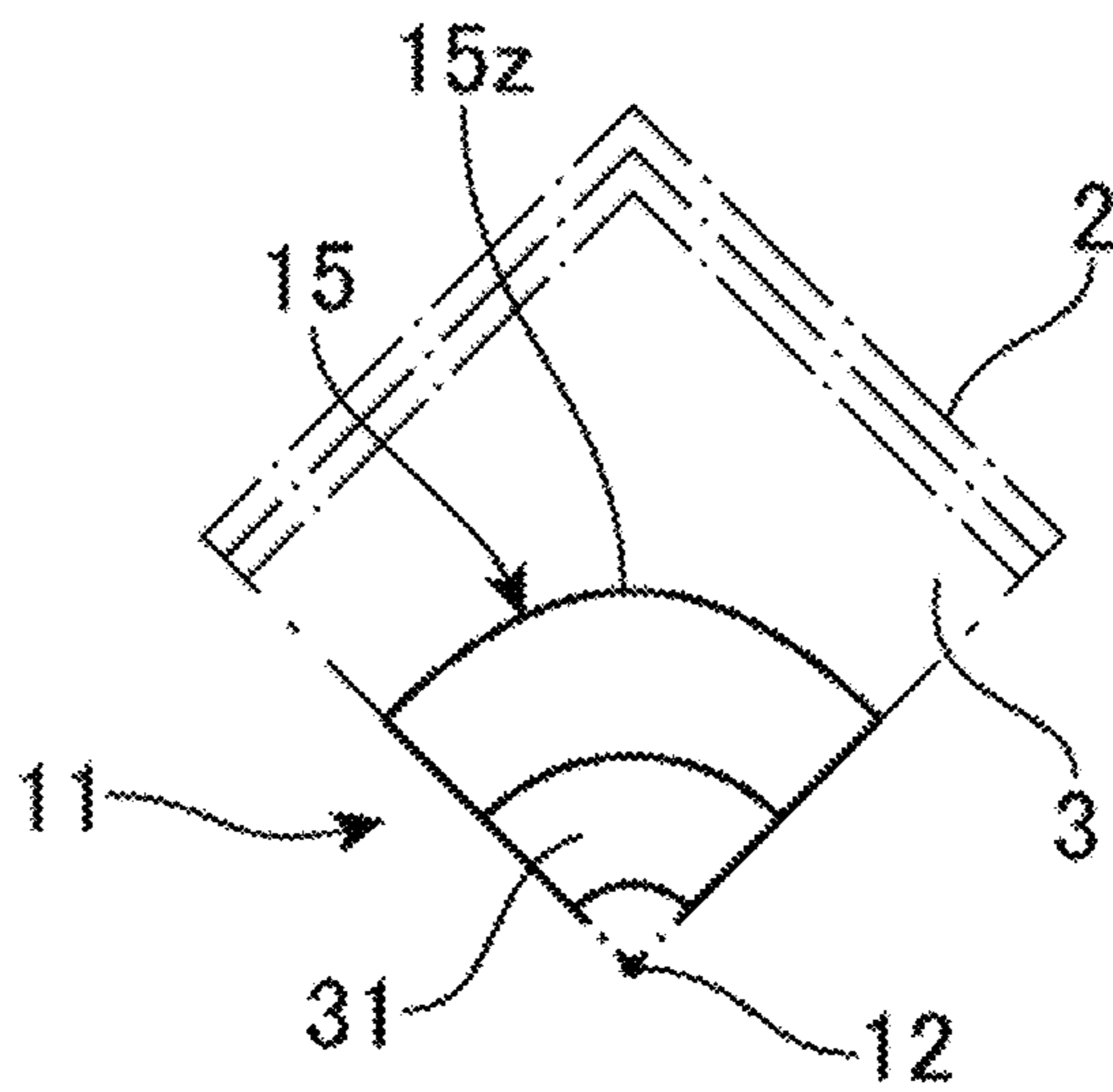


FIG. 21C

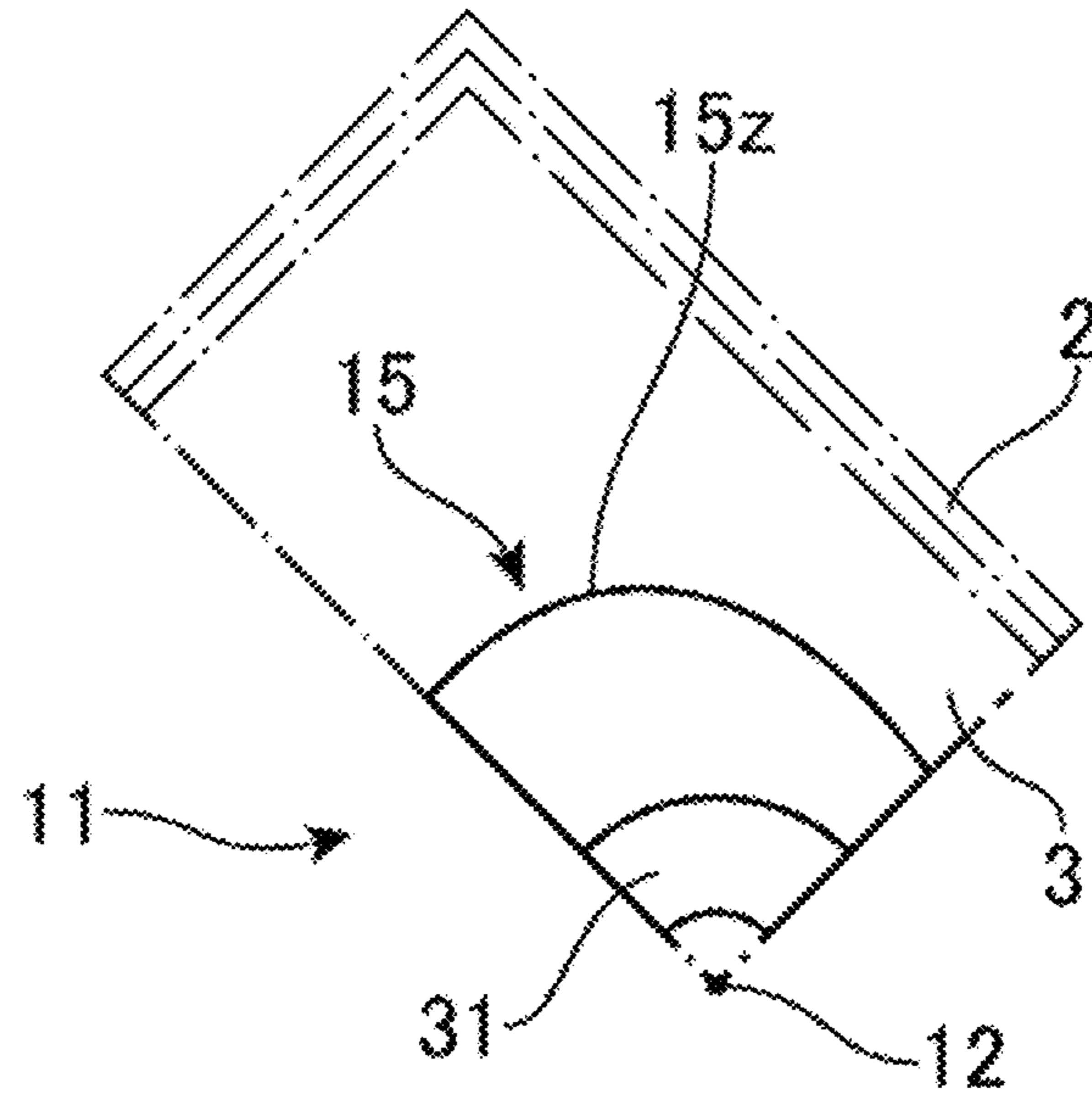


FIG. 22

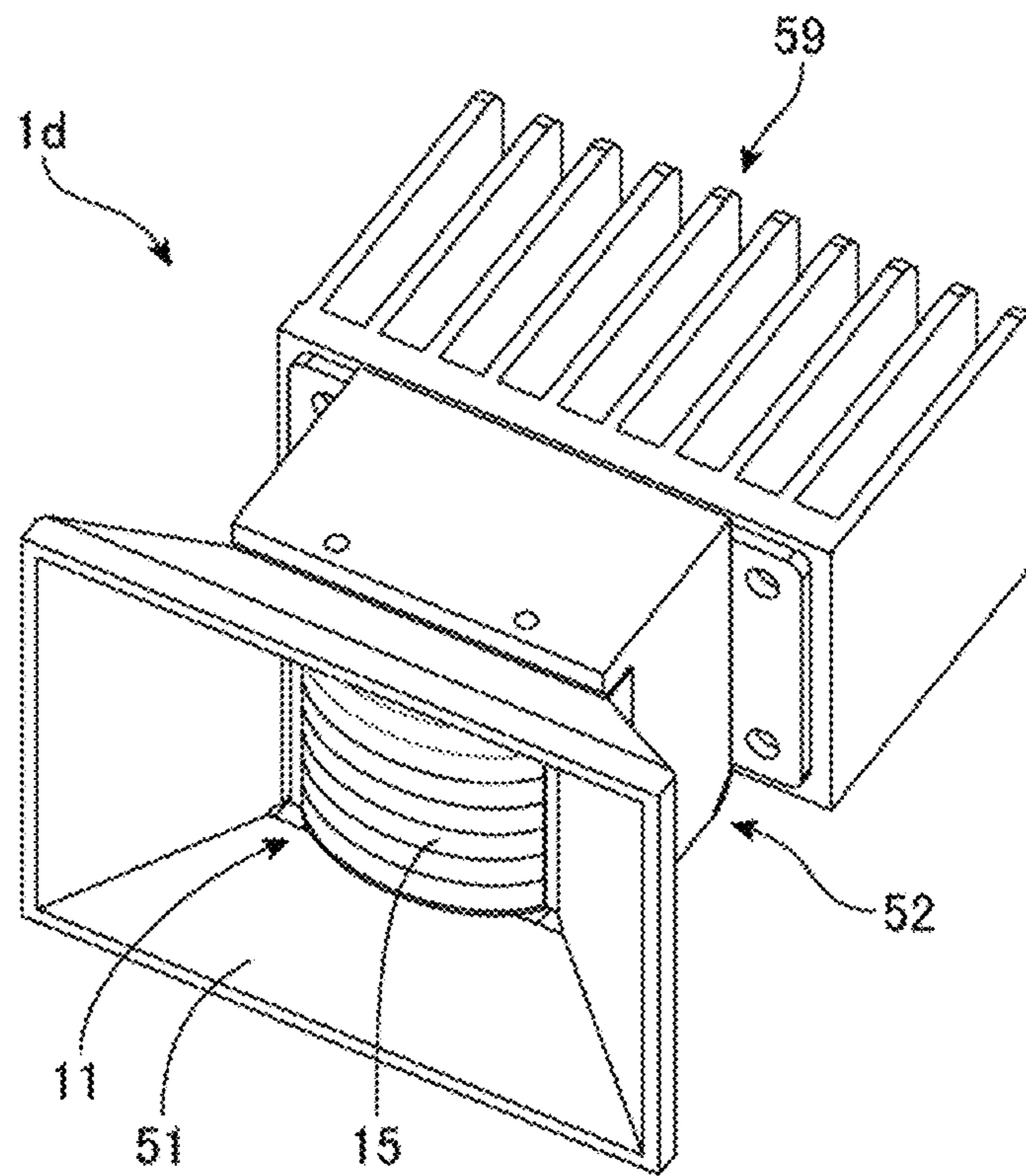


FIG. 23

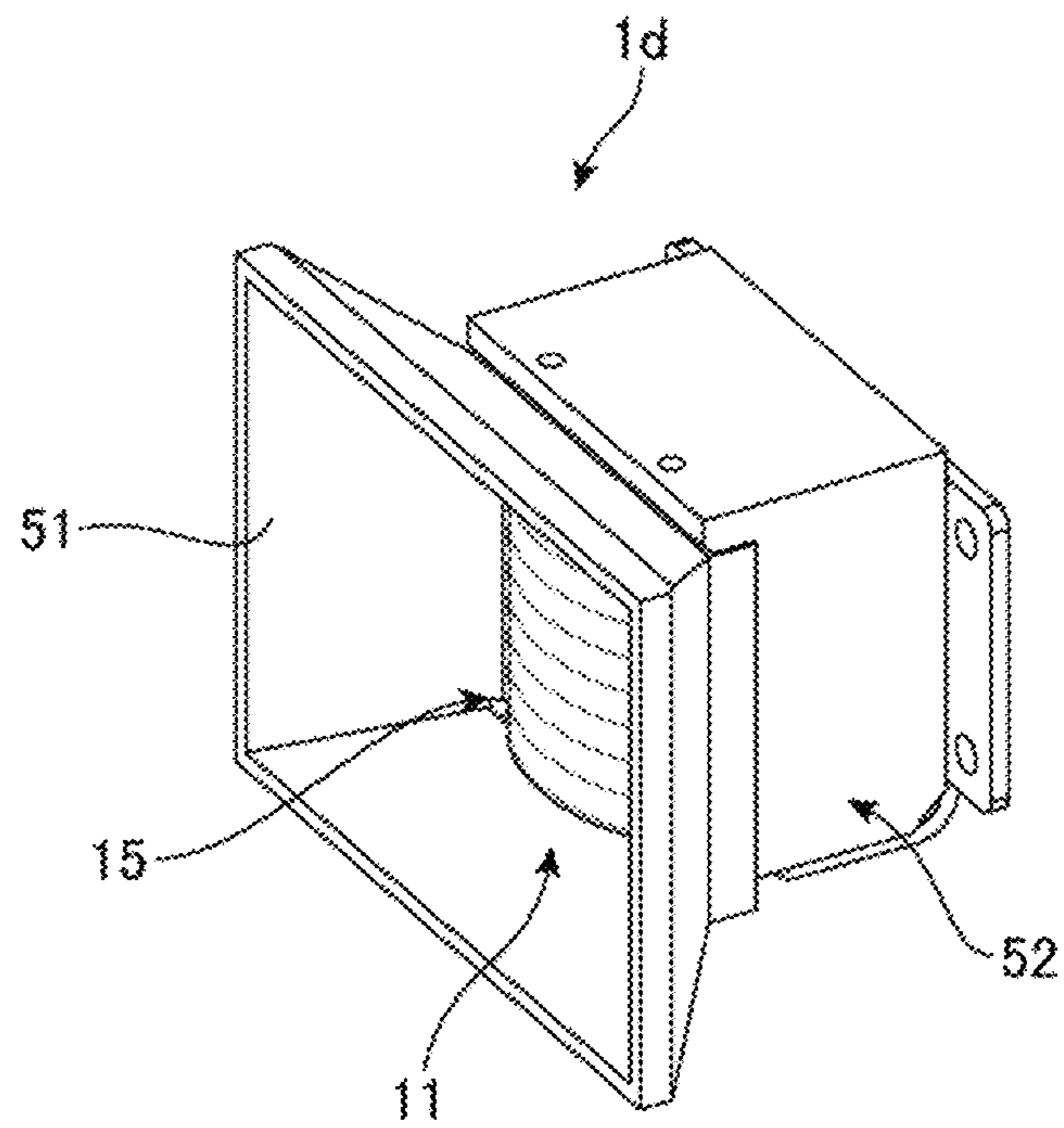


FIG. 24

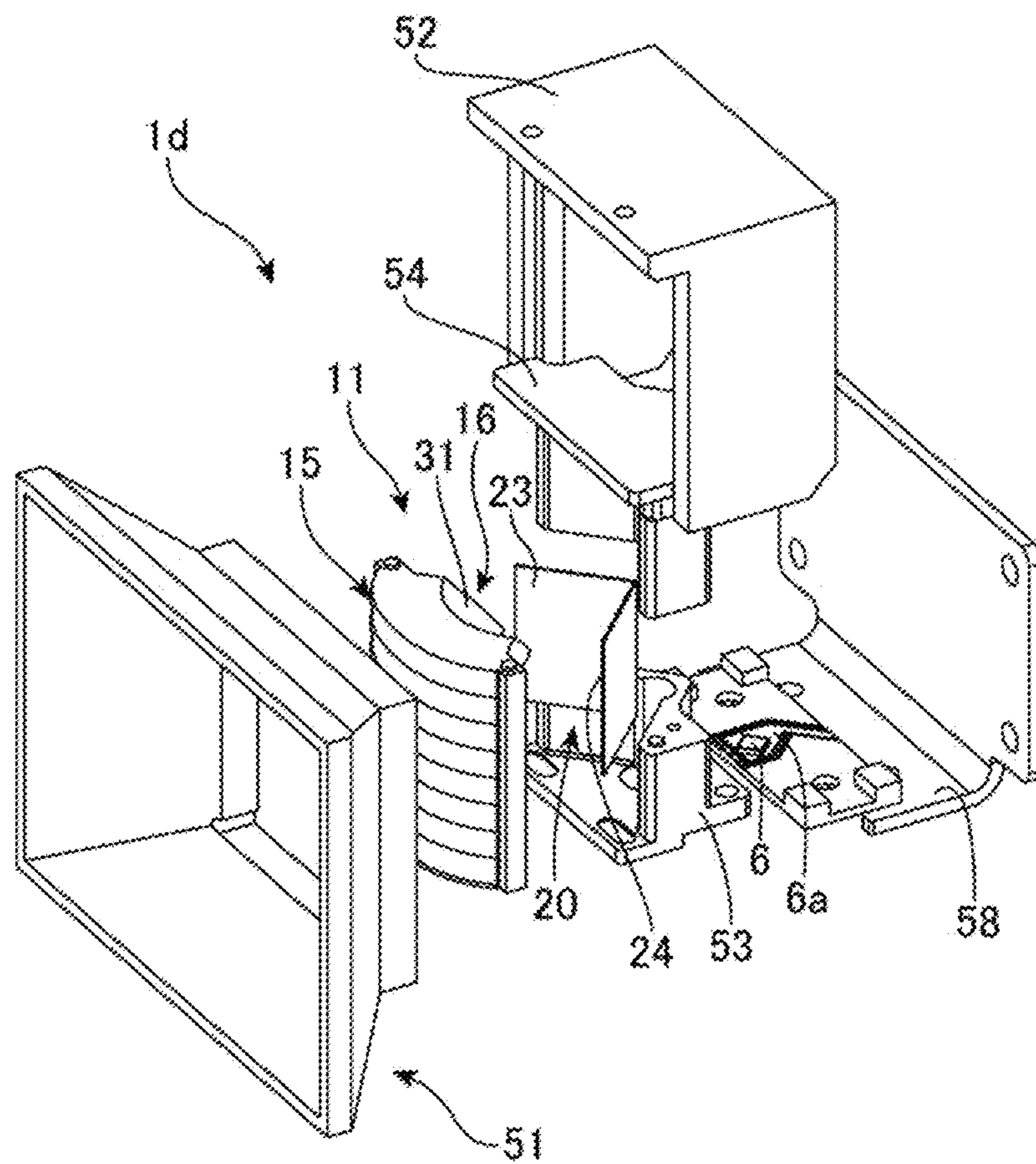


FIG. 25A

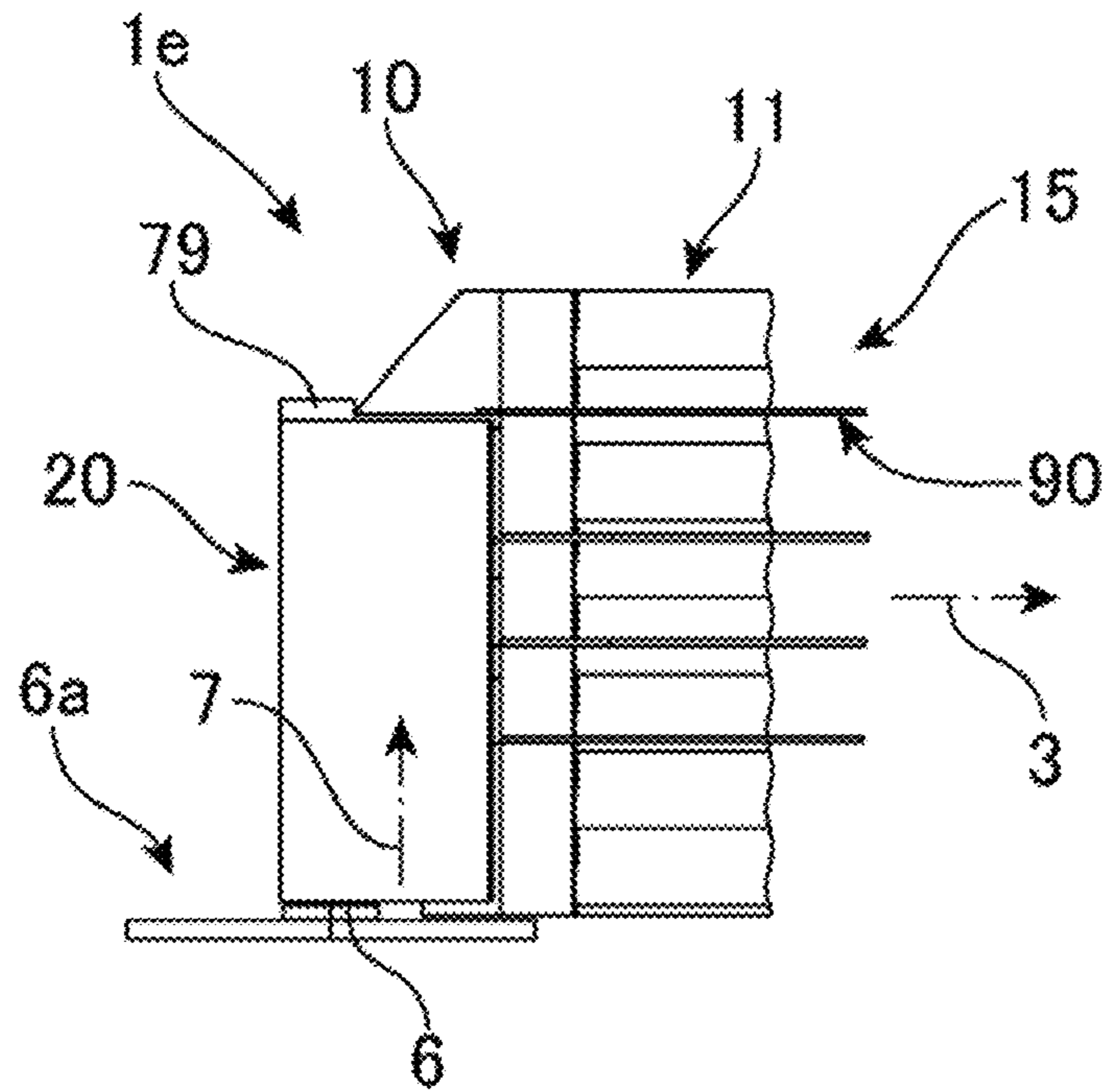


FIG. 25B

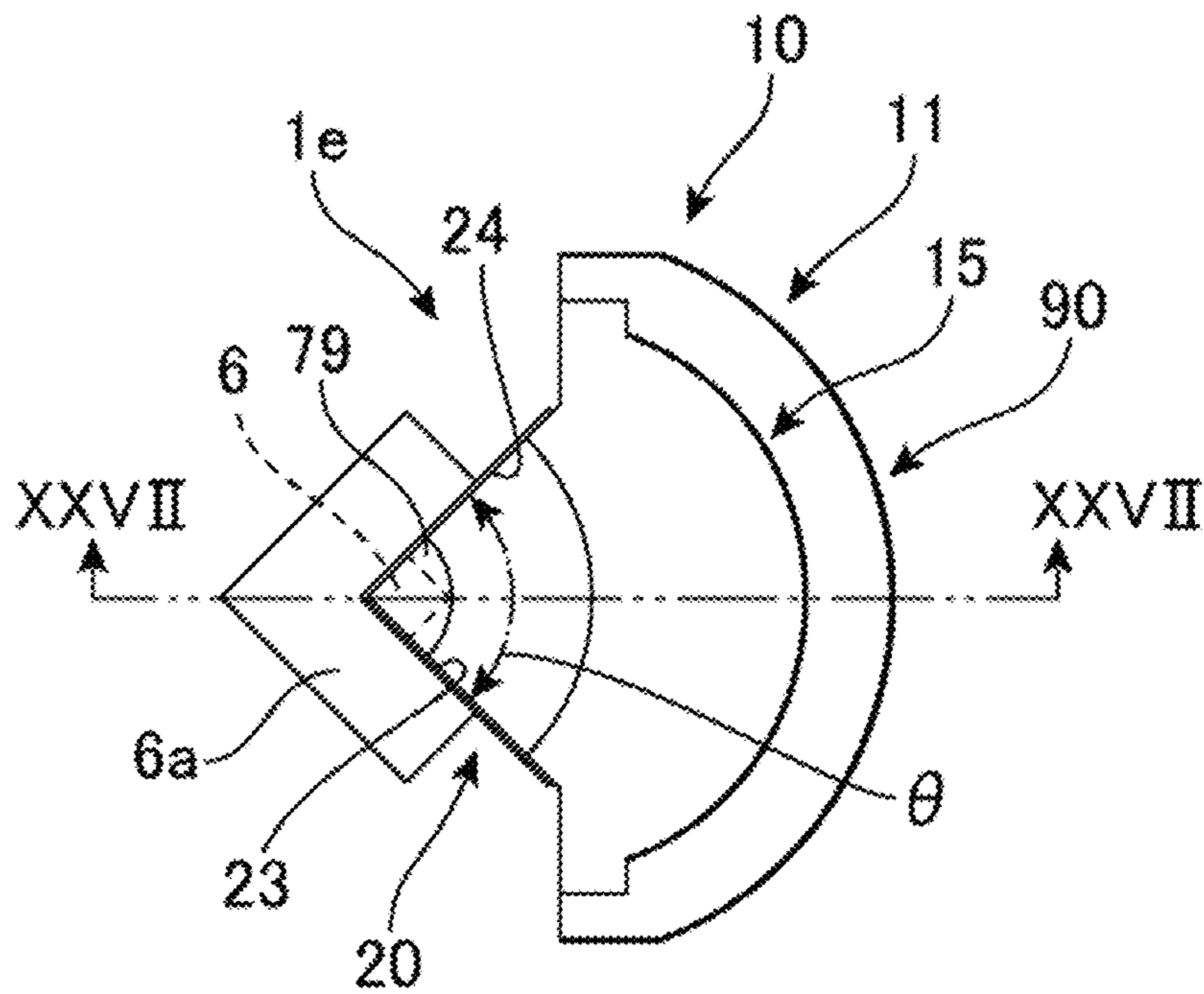


FIG. 26

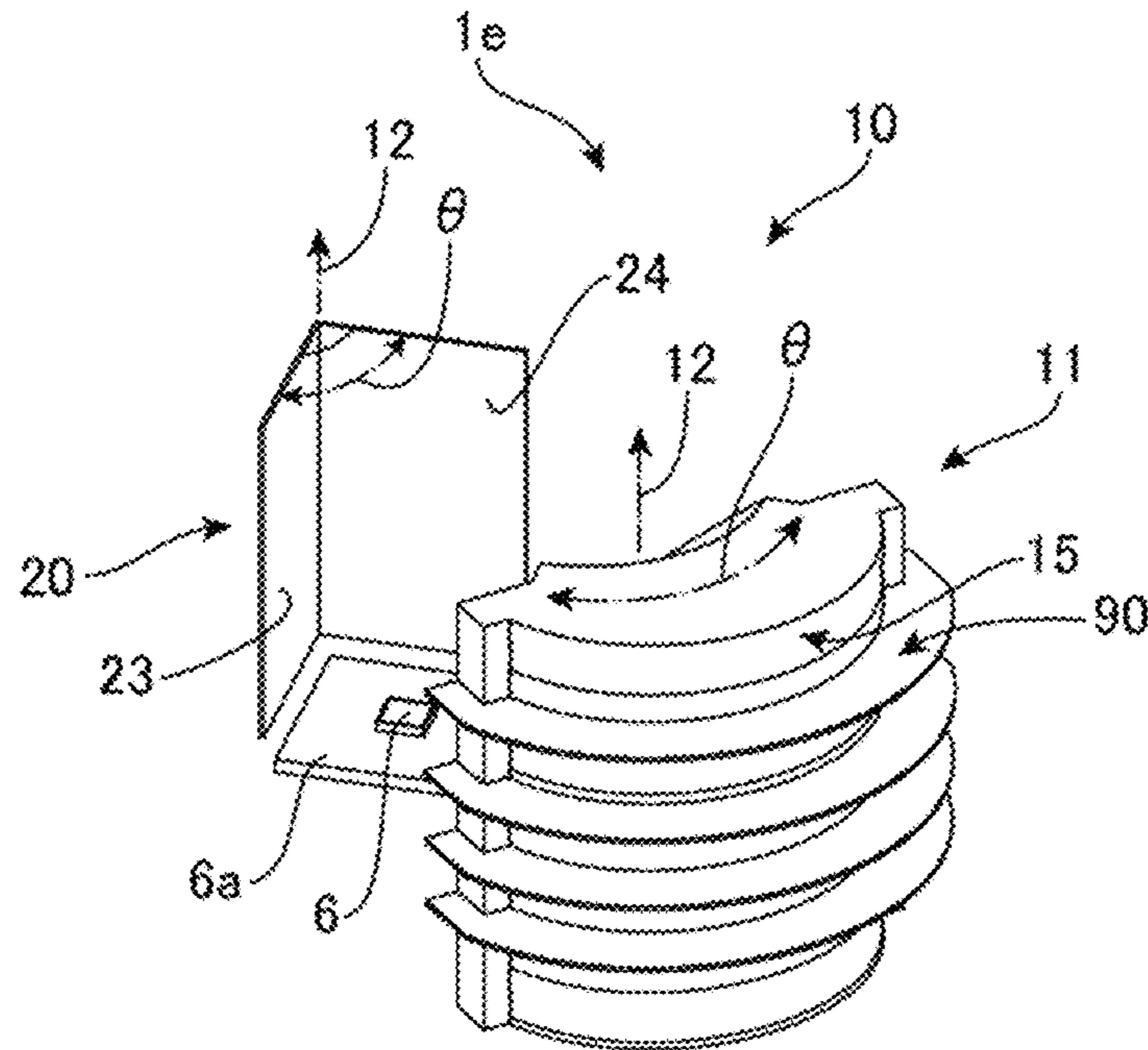


FIG. 27

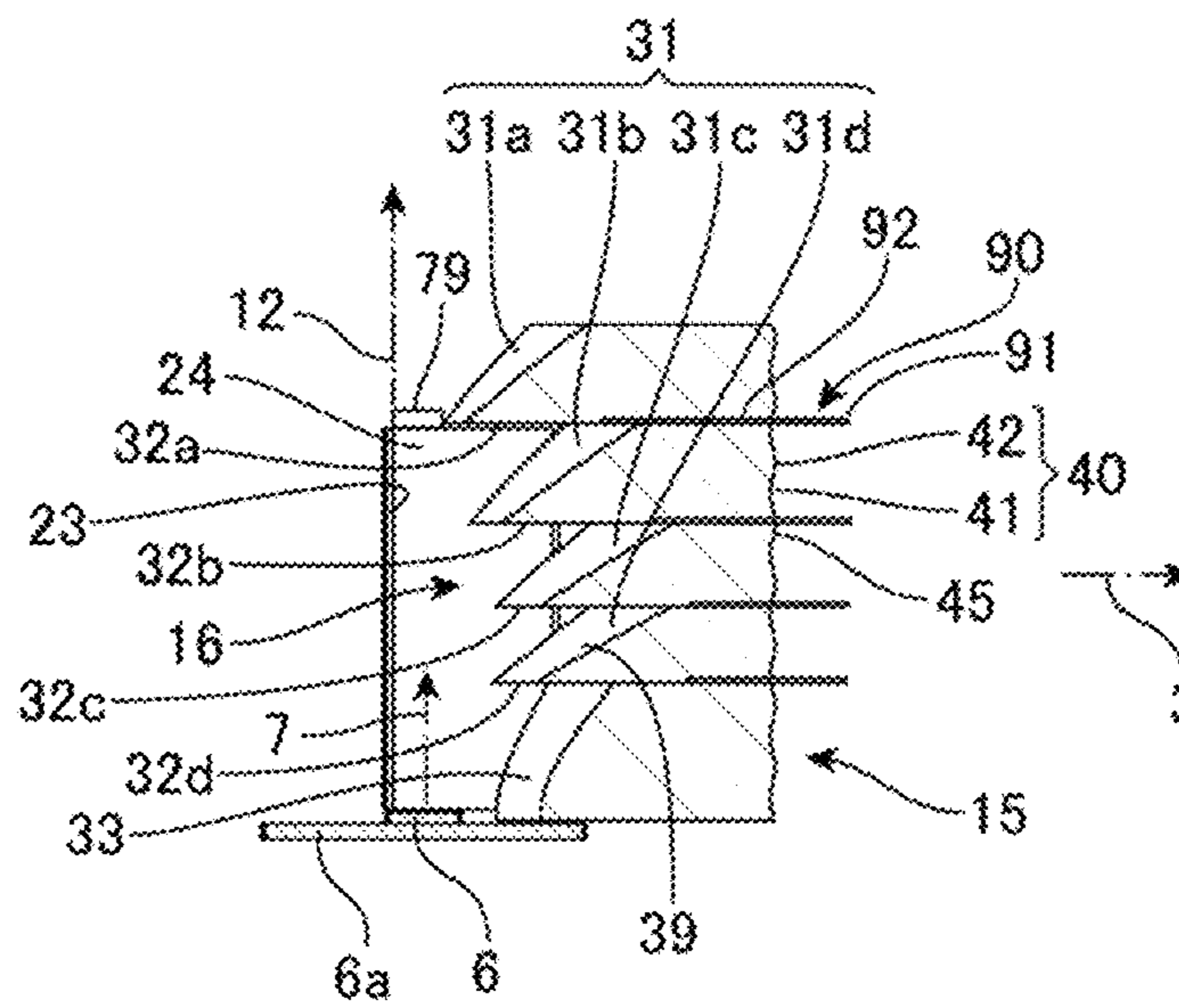


FIG. 28

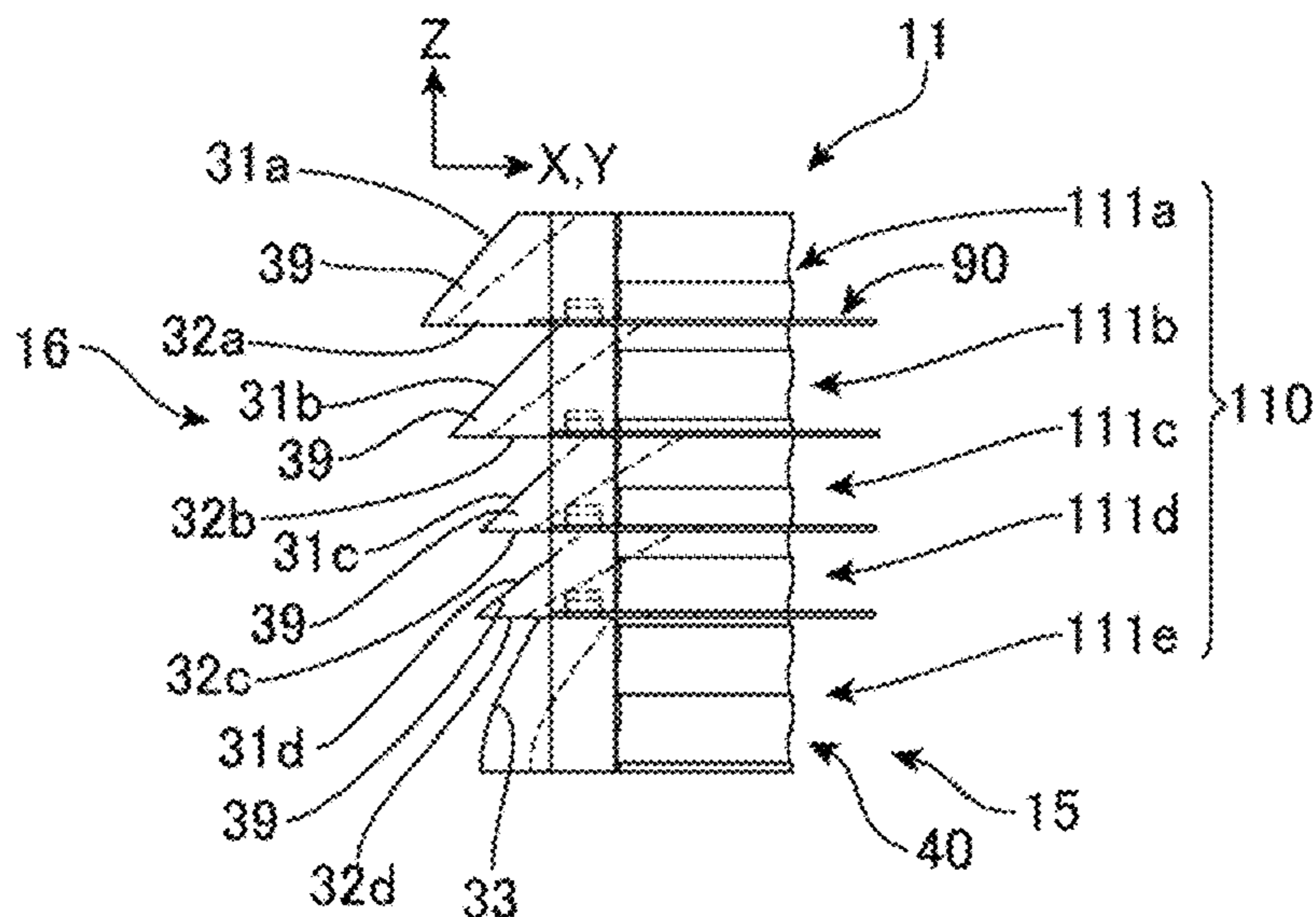


FIG. 29

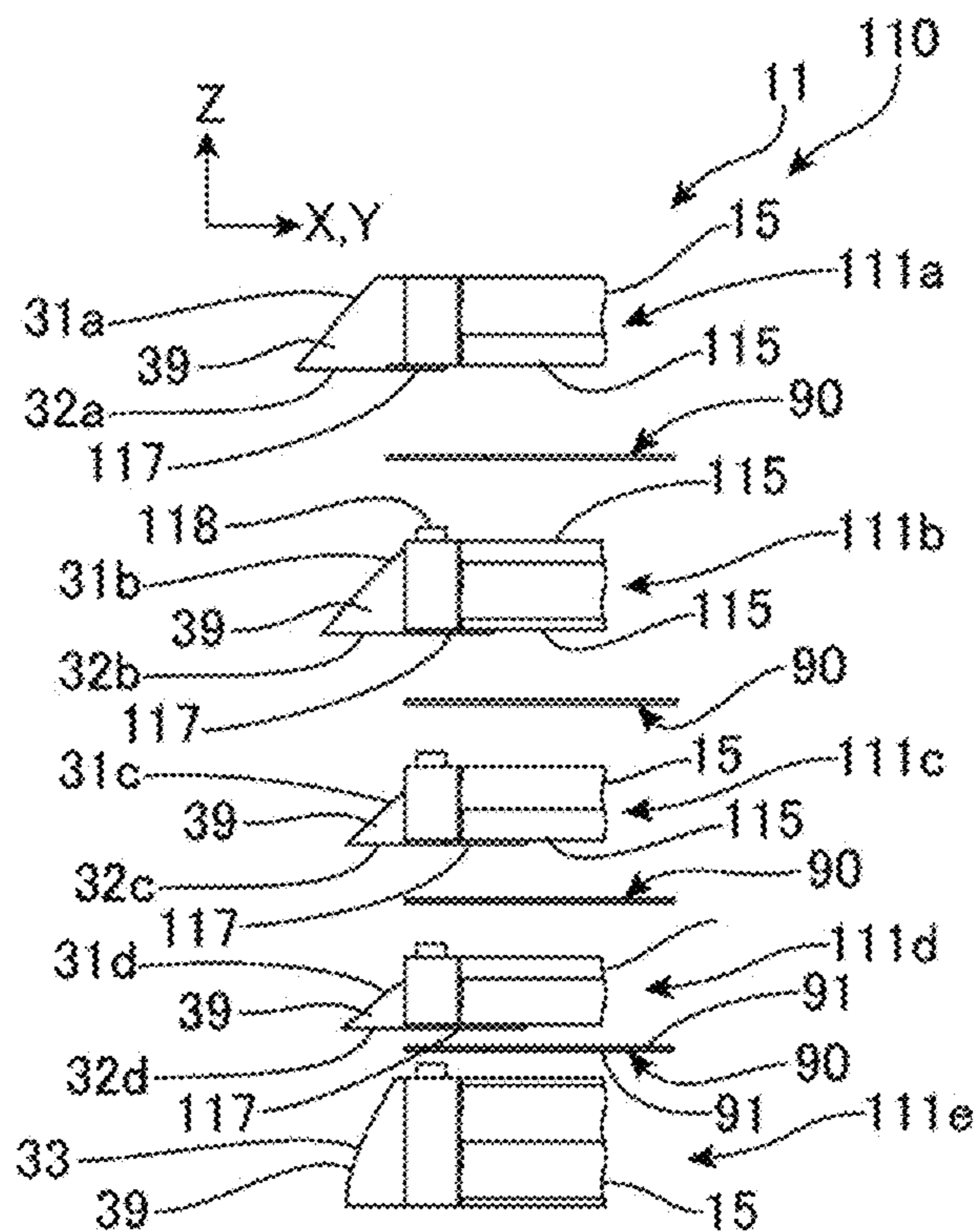


FIG. 30A

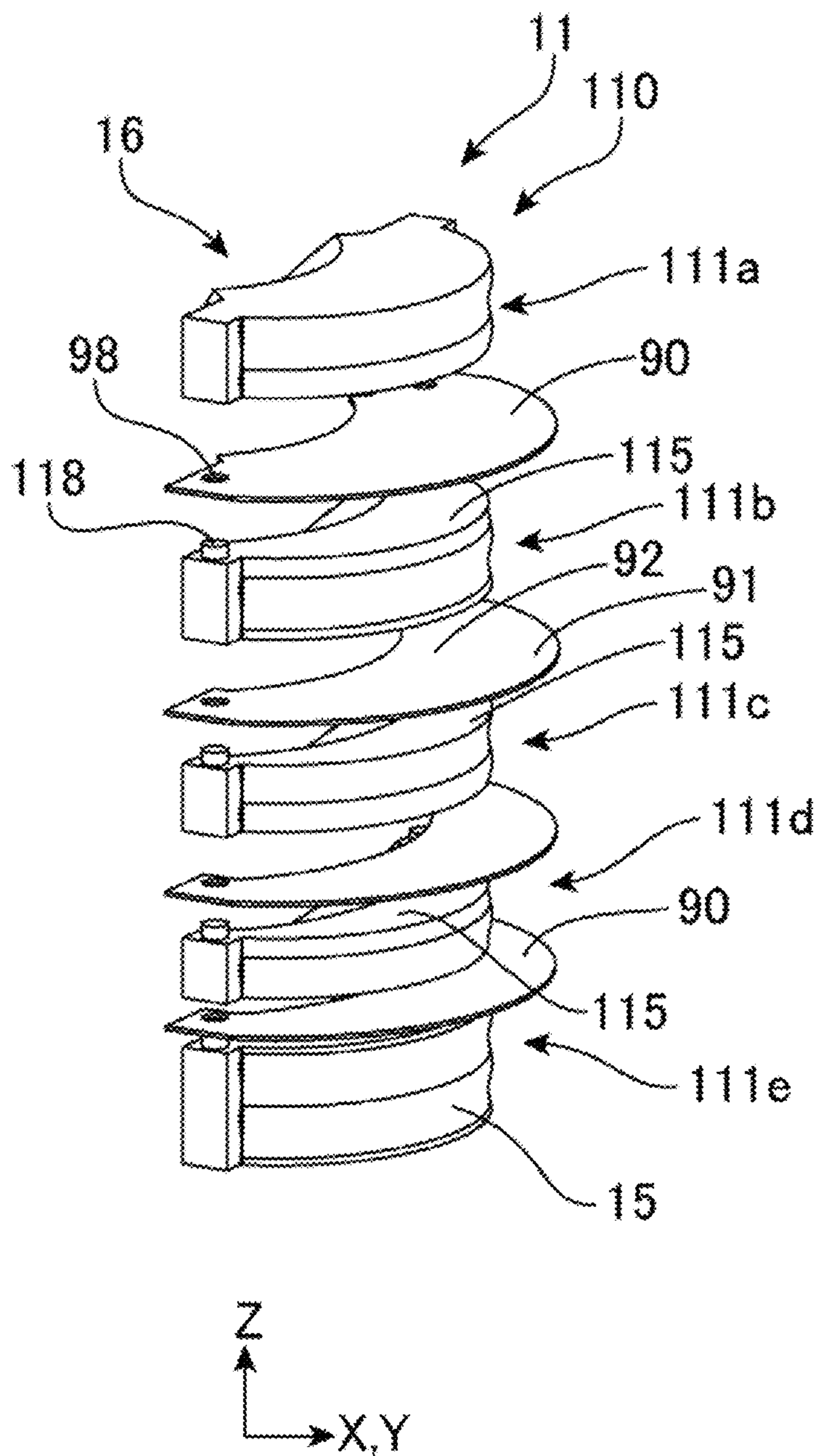


FIG. 30B

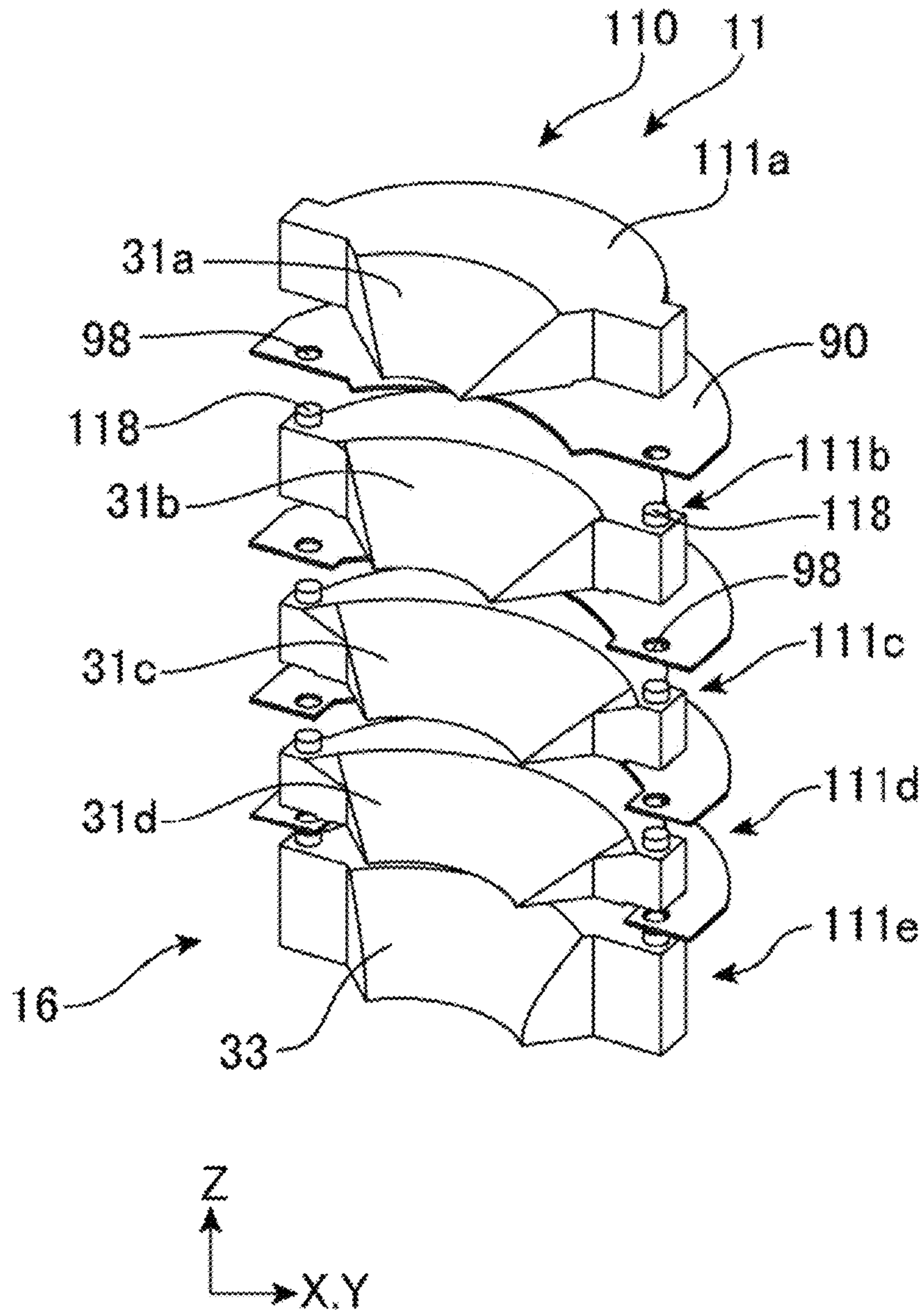


FIG. 30C

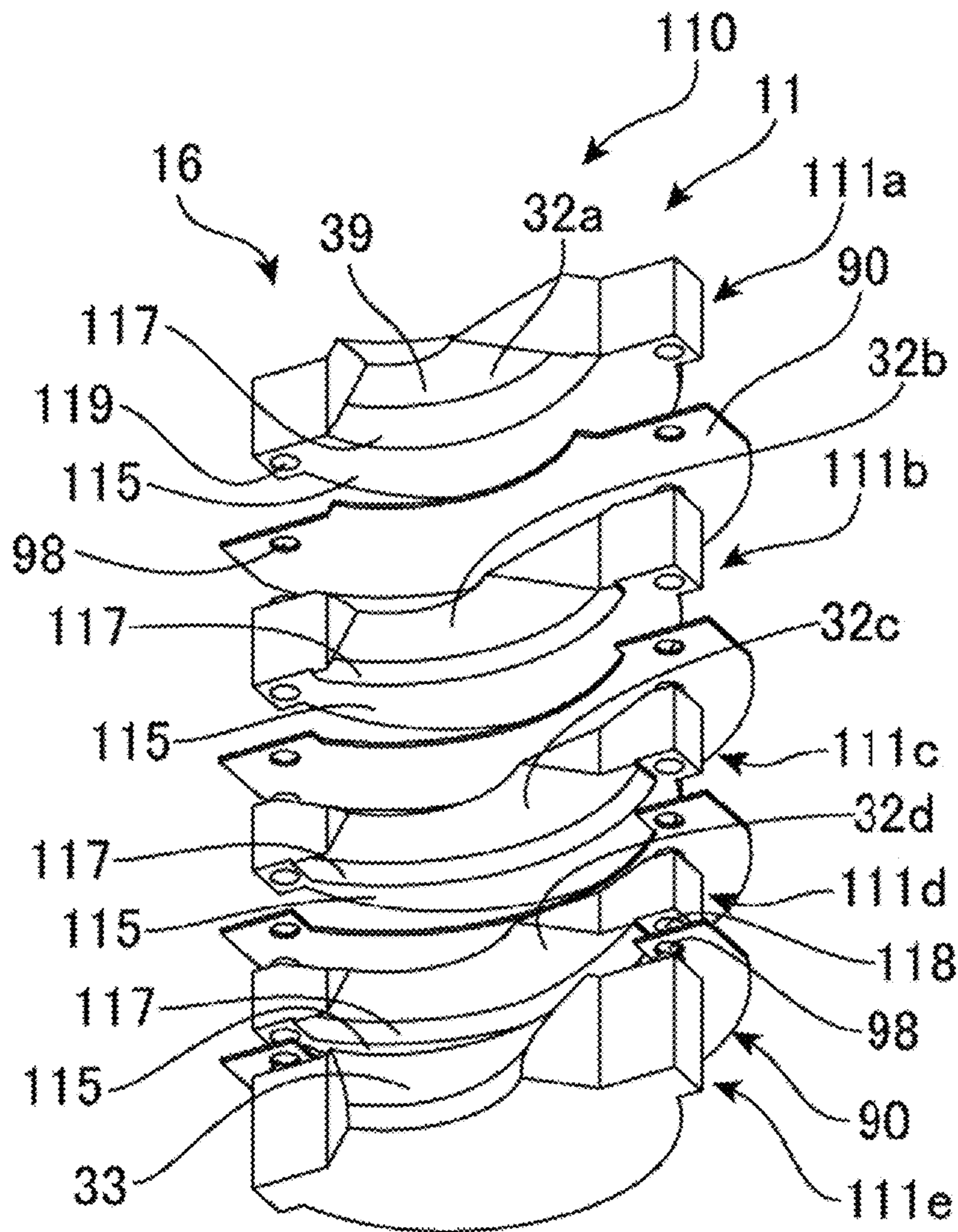


FIG. 31

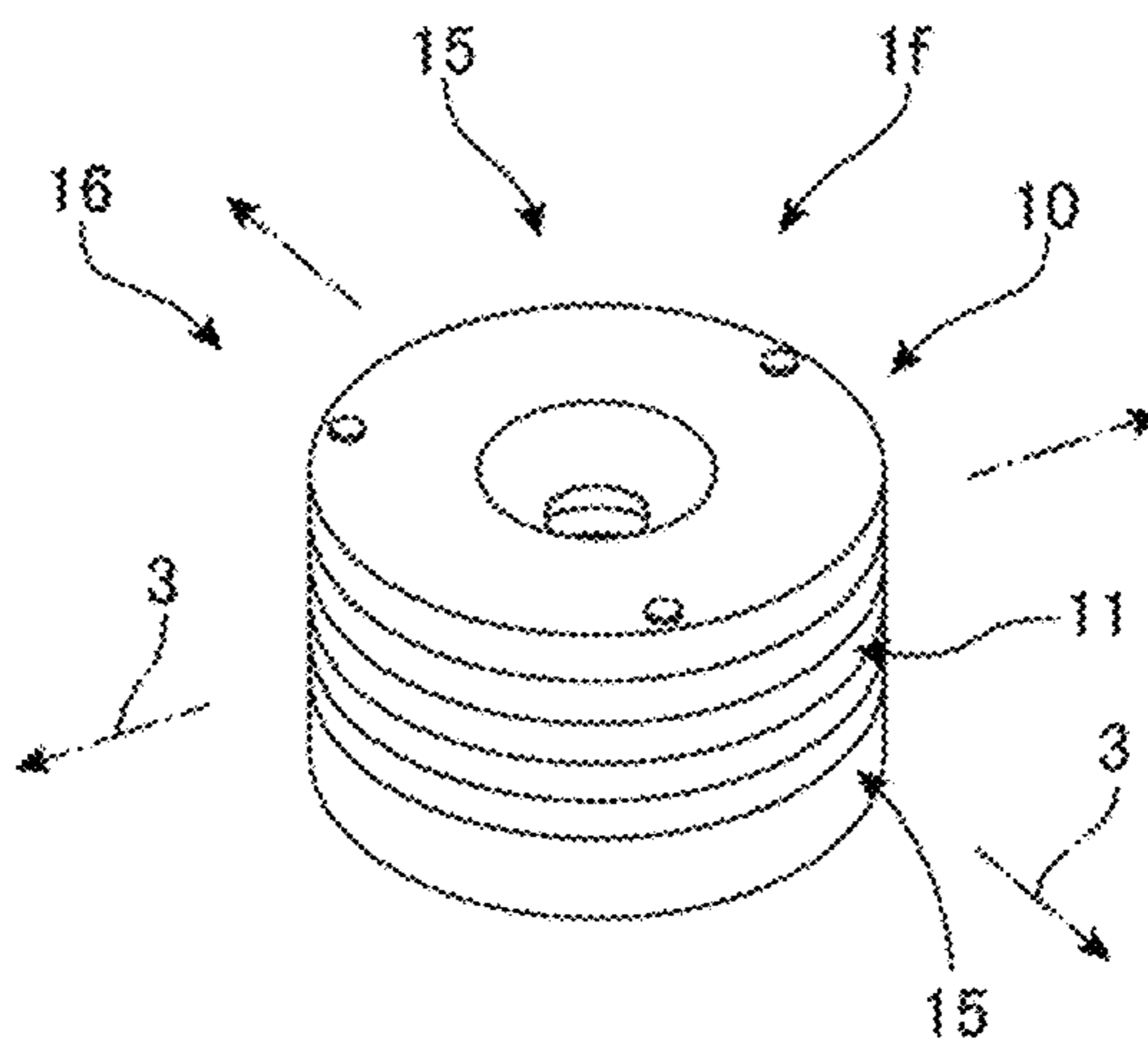


FIG. 32A

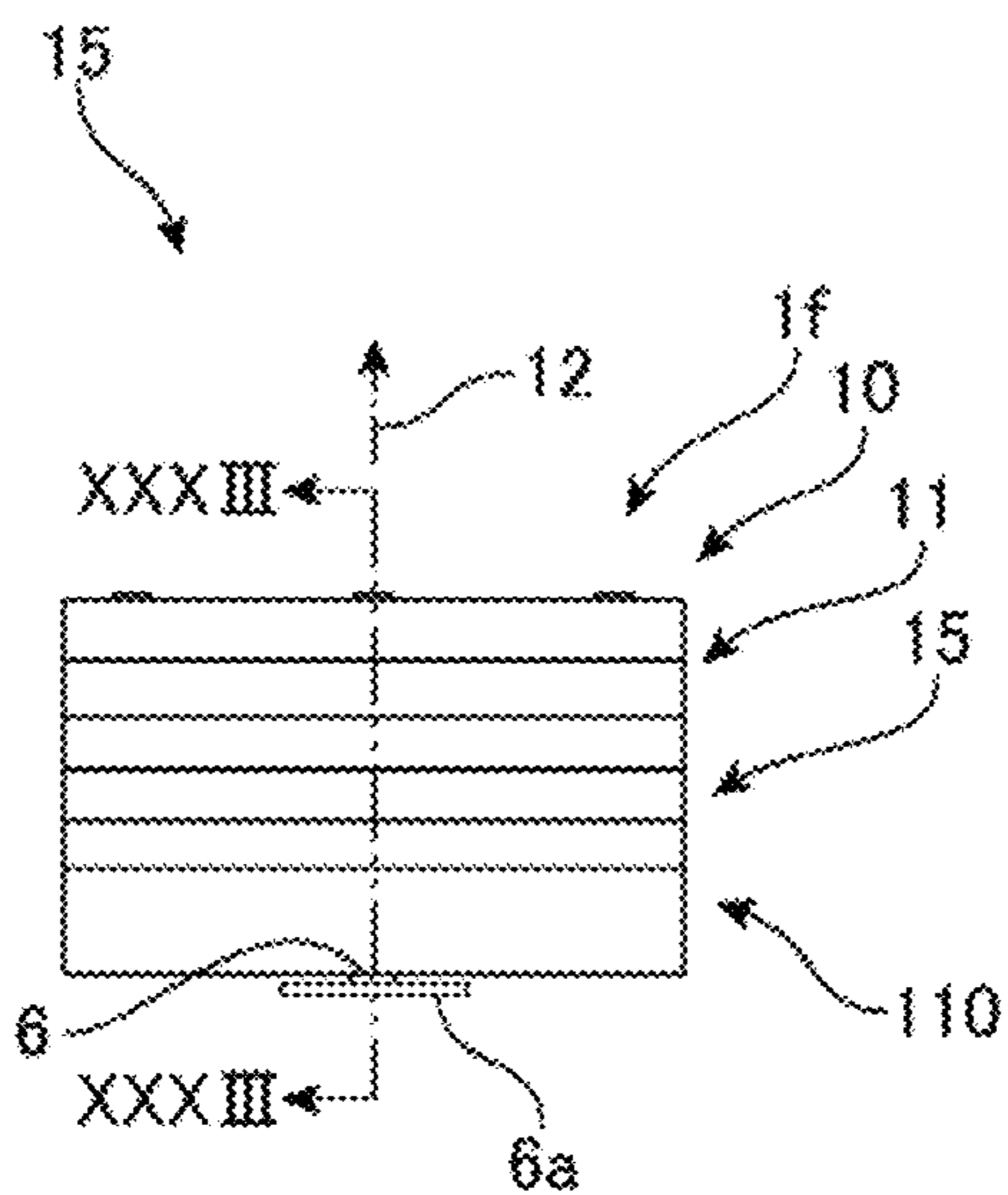


FIG. 32B

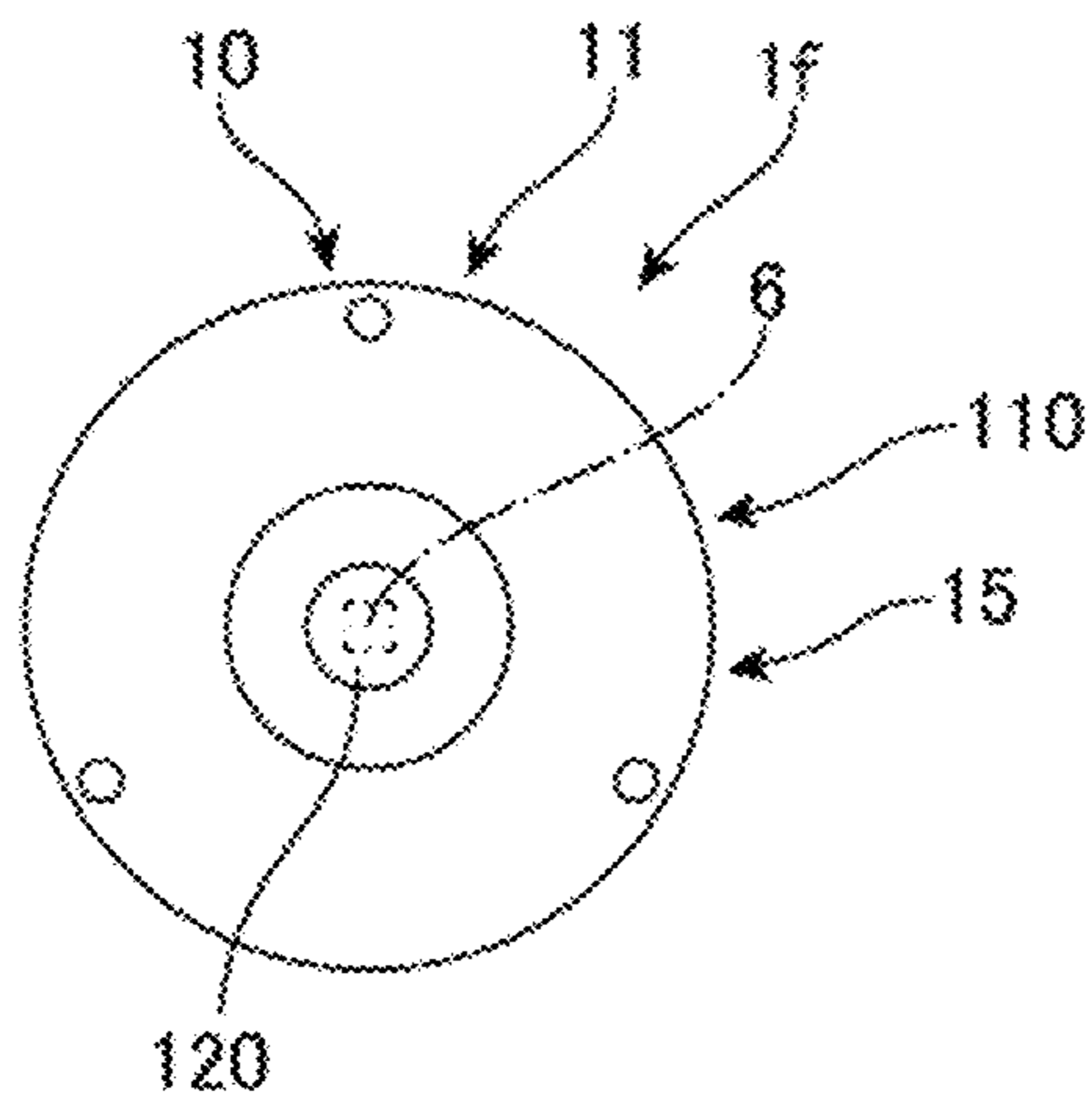


FIG. 33

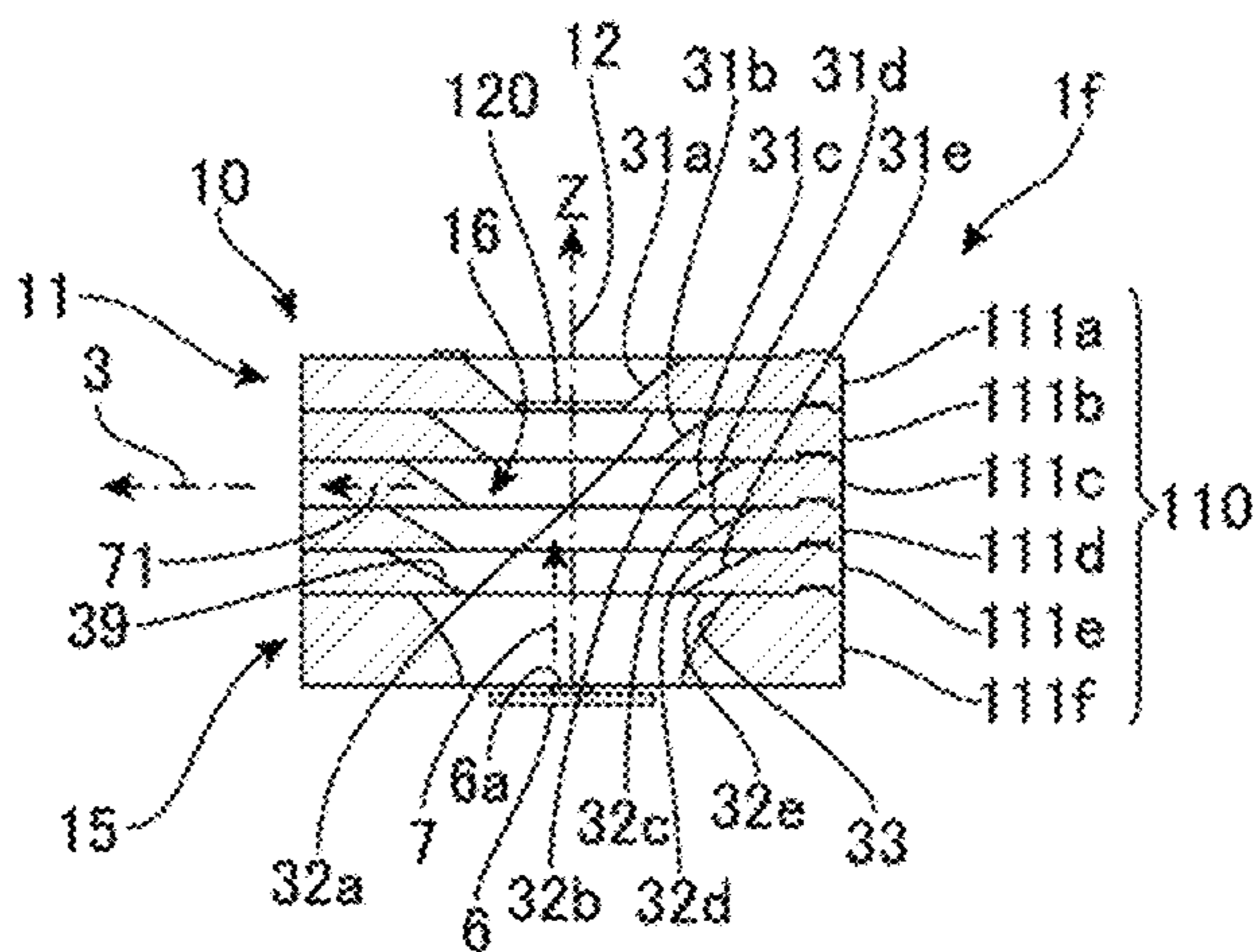


FIG. 34

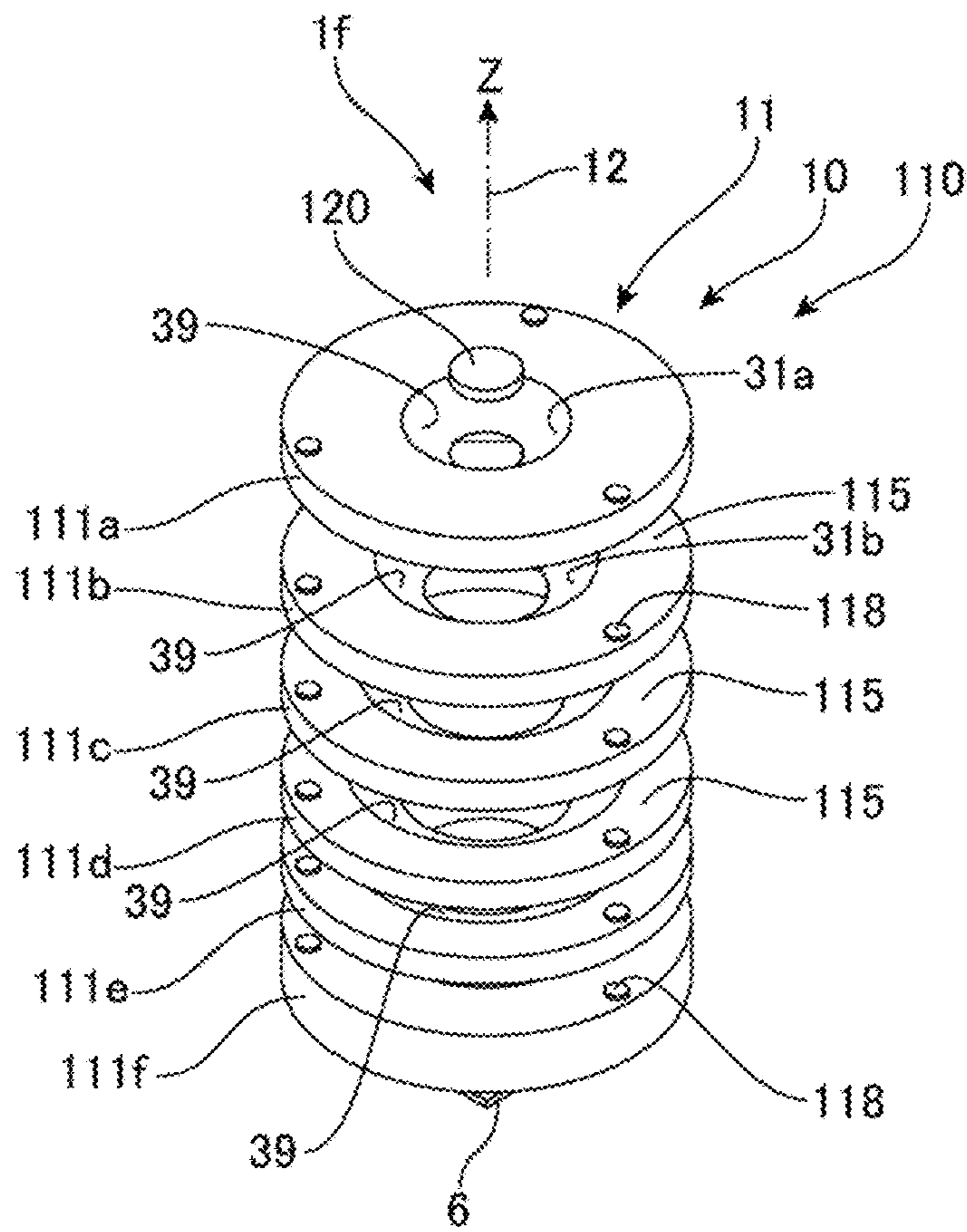


FIG. 35

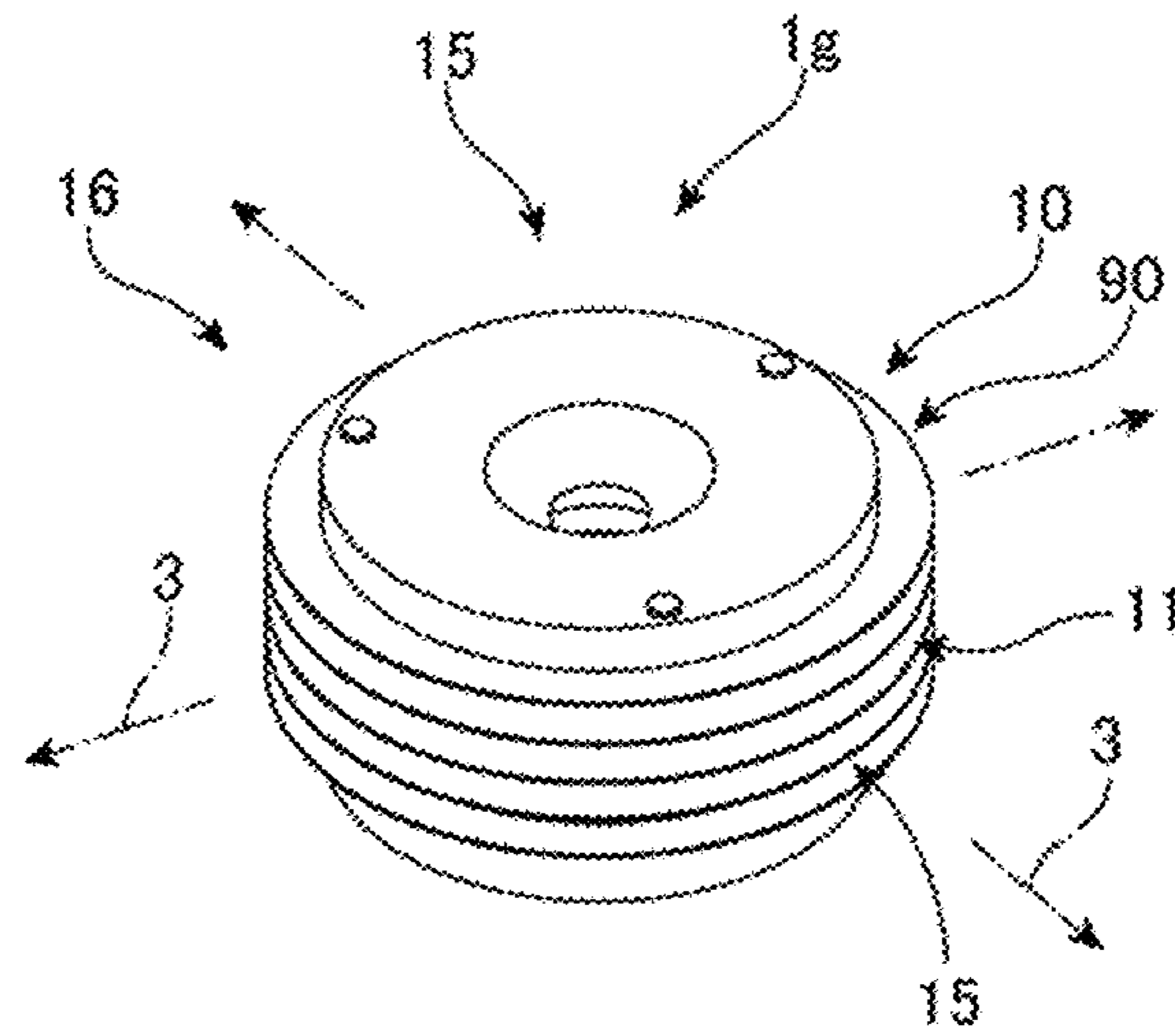


FIG. 36A

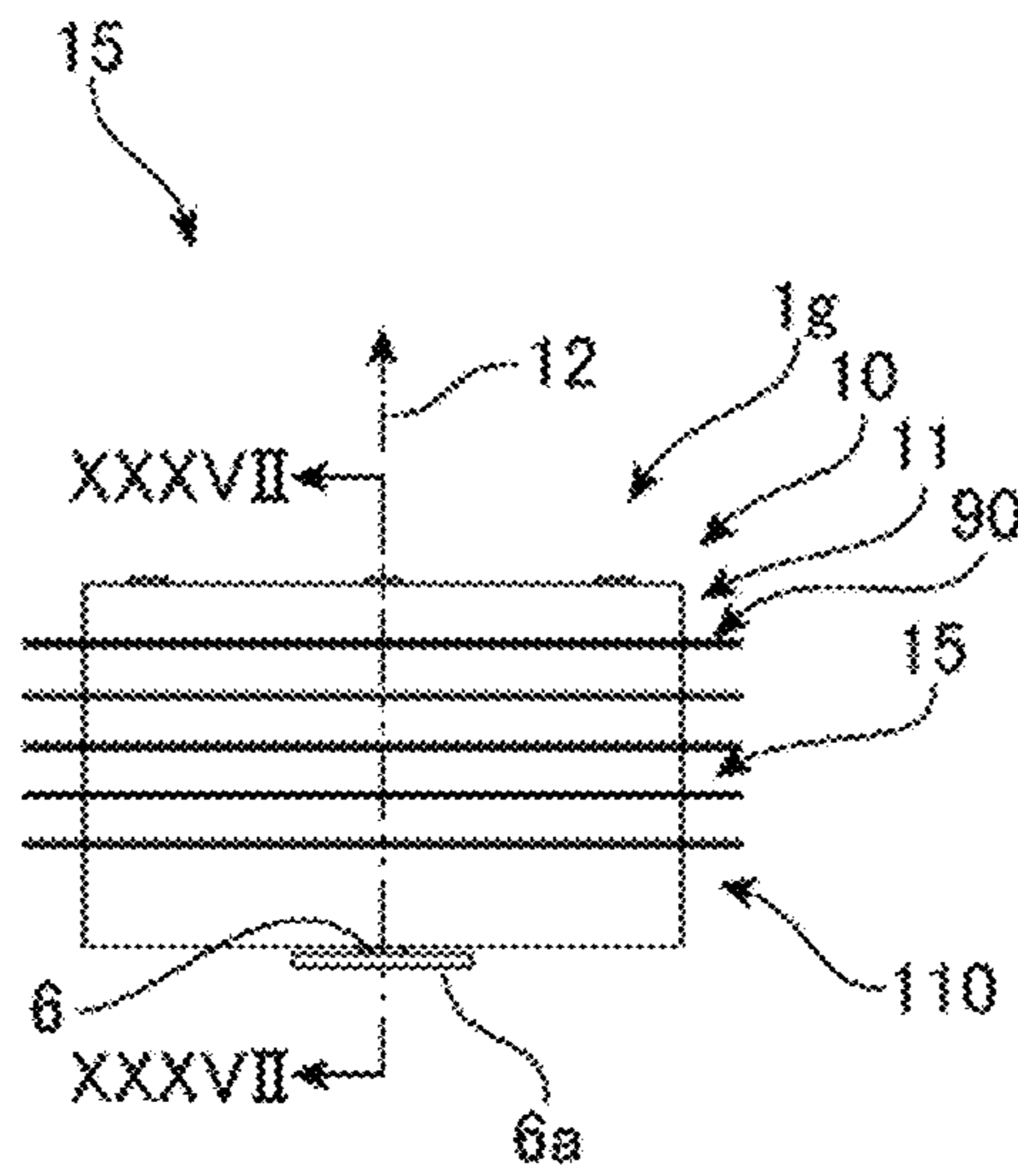


FIG. 36B

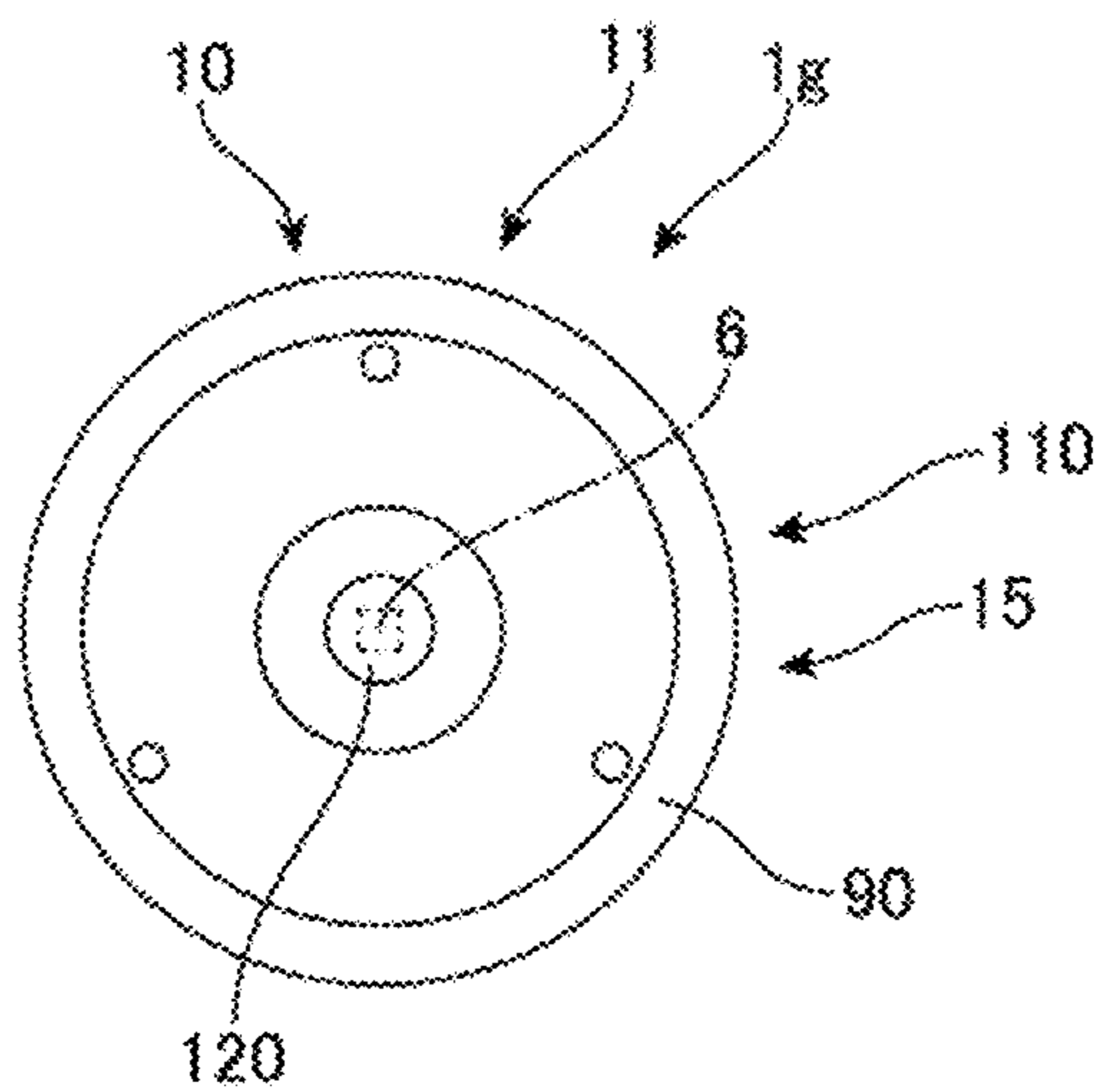


FIG. 37

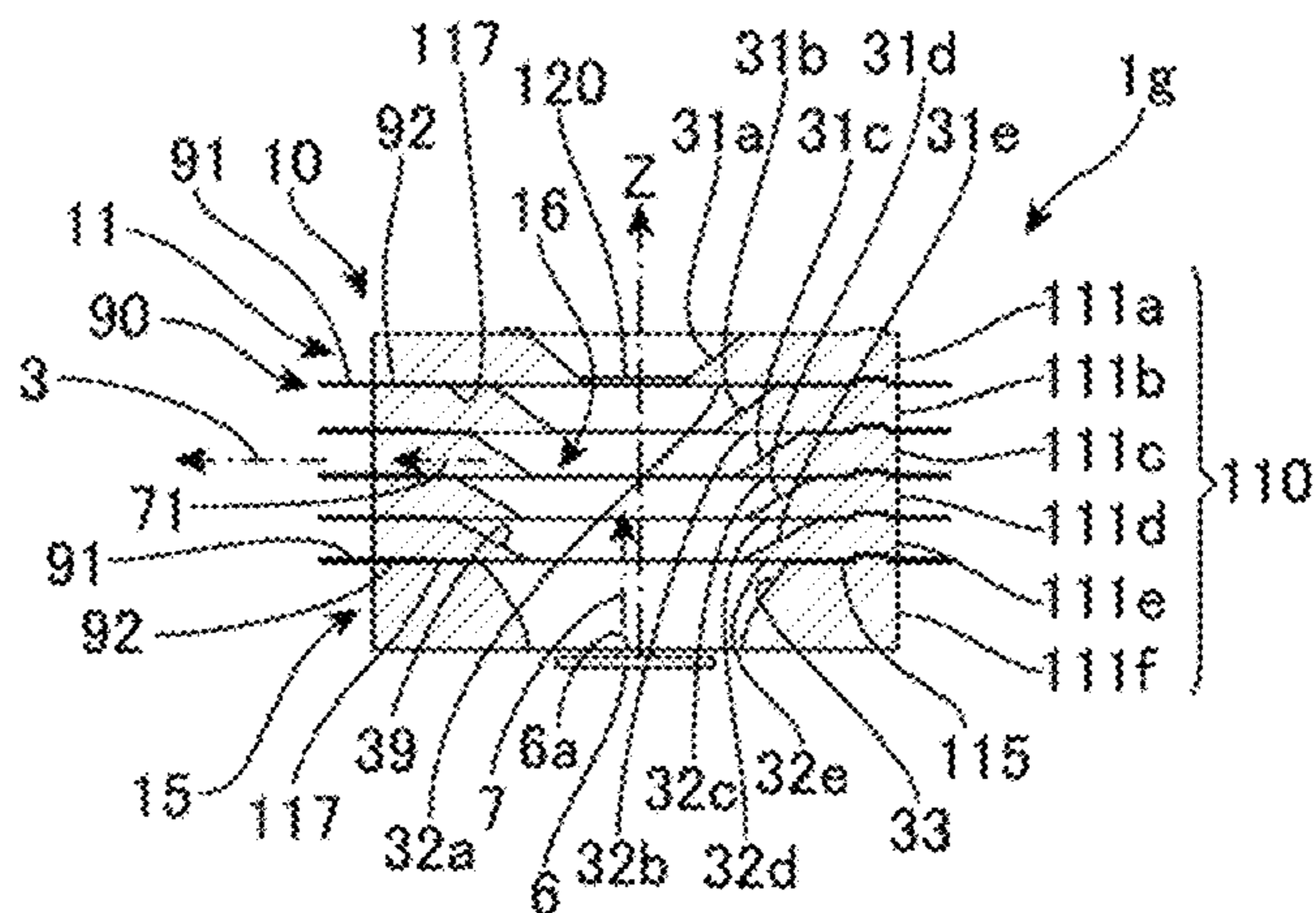
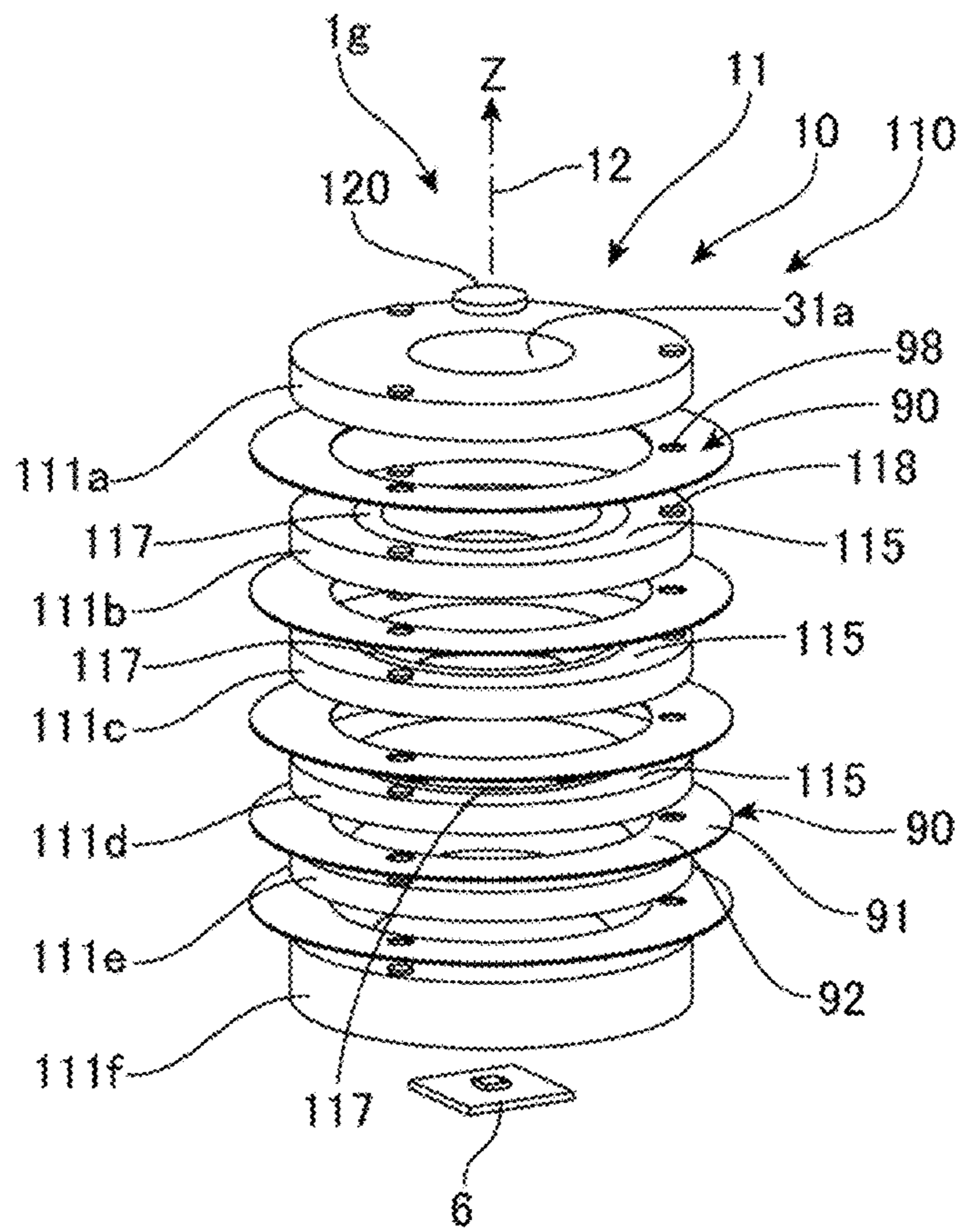


FIG. 38



OPTICAL DEVICE AND ILLUMINATION DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to Japanese Patent Applications No. 2019-119942, filed on Jun. 27, 2019, and Japanese Application No. 2019-119943, filed on Jun. 27, 2019, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present disclosure relates to an optical device appropriate for illumination of a region having a predetermined shape such as a linear shape or a quadrangular shape and an illumination device employing the optical device.

2. Description of Related Art

Japanese Unexamined Patent Application Publication No. 2012-074278 describes the provision of an illumination device configured to illuminate an irradiation region having an elongated linear shape using a small number of light source modules. The illumination device in Japanese Unexamined Patent Application Publication No. 2012-074278 includes light source units arranged in two rows, each row including four light source units. Each light source unit is composed of a pair of light source modules. The light source module distributes divergent light from a light-emitting element into a first emitted light that is emitted frontward with respect to a substrate through a light source lens and a second emitted light that is refracted through the light source lens, reflected by a second reflection plate, and emitted frontward with respect to the substrate. In the light source unit, the substrates of the two light source modules are arranged back to back at an acute angle, and the light source unit produces a linear illumination light having a uniform width and spreading at an angle between the substrate of one of the two light source modules and the substrate of the other of the two light source modules. Accordingly, the illumination device can irradiate the irradiation region having a long linear shape.

SUMMARY OF THE INVENTION

Light emitted from an LED generally has a Lambertian light distribution, which is a light distribution pattern in which the luminous intensity is highest (largest) on the optical axis. Accordingly, when illuminating an irradiation region of a long linear shape using a small number of or densely arranged illumination devices, the light distribution is required to be controlled by varying angles of a large number of optical axes of a large number of densely arranged LEDs to disperse light along the linear region to be illuminated or by performing different types of complicated processing to light illuminating an end portion of the line and light illuminating a central portion of the line on optical axes that are set obliquely across the linear region. Accordingly, there is a demand for an optical device configured to easily convert a Lambertian light distribution into a distribution of light appropriate for illumination of a region having a predetermined shape such as a linear shape or a quadrangular shape.

An optical device according to one embodiment of the present invention includes: a first reflective surface disposed to reflect, to a substantially arc-shaped first region around a first axis, at least a portion of first light incident along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis, the first reflective surface including a plurality of reflective arc surfaces separated in a direction along the first axis; a second reflective surface and a third reflective surface intersecting each other on the first axis and disposed such that the first reflective surface is located between the second reflective surface and the third reflective surface; and a light-transmissive emission surface adapted to refract at least a portion of light reflected by the plurality of reflective arc surfaces to emit the light around the first axis, the emission surface having periodic irregularities in a cross section in the direction along the first axis.

An illumination device according to another embodiment of the present invention includes the optical device described above and a light source adapted to emit the first light.

In the optical device according to certain embodiments of the present invention, light (first light) incident along the first axis is reflected at the first reflective surface disposed around the first axis to form an arc shape toward a direction perpendicular to the first axis to collimate the reflected light, and the collimated light is refracted by the emission surface and is emitted as illumination light. Accordingly, light with a Lambertian light distribution can be converted into light with a light distribution appropriate for a linear shape region or a quadrangular shape region to be illuminated having a shape such as a linear shape or a quadrangular shape before being emitted.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic perspective view showing one example of an illumination device.

FIG. 2 schematically shows an example in which the illumination device is attached to the ceiling.

FIG. 3A schematically shows a projection unit when viewed from a front side (when viewed opposite to the direction of radiation).

FIG. 3B schematically shows the projection unit when viewed from a side of the Z-axis.

FIG. 4 is a schematic exploded view of the projection unit.

FIG. 5 is a schematic cross-sectional view of a structure of an optical element.

FIG. 6A schematically shows the distribution of incident light.

FIG. 6B schematically shows reflection of the incident light by reflective surfaces 31 of an optical element 11.

FIG. 7A and FIG. 7B schematically show examples of the distribution of emitted light.

FIG. 8 is a schematic cross-sectional view of another example of the illumination device.

FIG. 9A and FIG. 9B schematically show an example of illumination obtained by the illumination device.

FIG. 10 schematically shows another example of illumination obtained by the illumination device.

FIG. 11A and FIG. 11B schematically show another example of light leakage caused when using the illumination device.

FIG. 12 is a schematic cross-sectional view of still another example of the illumination device.

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FIG. 13A and FIG. 13B are a schematic lateral view and a schematic plan view, respectively, of yet another example of the illumination device.

FIG. 14 is a schematic exploded view of the illumination device in FIGS. 13A and 13B showing individual elements.

FIG. 15 is a schematic cross-sectional view of the illumination device shown in FIGS. 13A and 13B.

FIG. 16 schematically shows processing of light in the illumination device.

FIG. 17 schematically shows the incidence efficiency of light from a light source of the illumination device.

FIG. 18A and FIG. 18B are a schematic plan view and a schematic cross-sectional view, respectively, showing an example of relationship between a region to be illuminated and an optical element.

FIG. 19A, FIG. 19B, and FIG. 19C are a schematic plan view, a schematic cross-sectional view, and another schematic cross-sectional view, respectively, showing various examples of a relationship between a region to be illuminated and an optical element.

FIGS. 20A to 20C schematically show various examples of a relationship between a region to be illuminated and an optical element, in which FIG. 20A schematically shows an optical element with a narrow light distribution, FIG. 20B schematically shows an optical element with a broad light distribution, and FIG. 20C schematically shows an optical element appropriate for illuminating a circular region.

FIGS. 21A to 21C schematically show various examples of a relationship between a region to be illuminated and an optical element, in which FIG. 21A shows a schematic cross-sectional view of an optical element appropriate for illumination of a U-shaped region, FIG. 21B shows a schematic cross-sectional view of an optical element appropriate for illumination of a V-shaped region, and FIG. 21C shows a schematic cross-sectional view of an optical element appropriate for illumination of an L-shaped region.

FIG. 22 is a schematic perspective view of even another example of illumination device.

FIG. 23 is a schematic perspective view of the illumination device shown in FIG. 22 in which illustration of a heat dissipating unit is omitted.

FIG. 24 is a schematic exploded view of the illumination device shown in FIG. 23.

FIG. 25A and FIG. 25B are a schematic side view and a schematic plan view, respectively, of further another example of the illumination device.

FIG. 26 is a schematic exploded view of the illumination device shown in FIGS. 25A and 25B showing individual elements.

FIG. 27 is a schematic cross-sectional view of the illumination device shown in FIGS. 25A and 25B.

FIG. 28 is a schematic side view of an optical element.

FIG. 29 is a schematic side view of the optical element divided into parts.

FIG. 30A to FIG. 30C are schematic exploded view of the optical element showing individual parts, in which FIG. 30A is viewed from the emission surface side, FIG. 30B schematically shows the inside of the optical element viewed from obliquely above, FIG. 30C schematically shows the inside of the optical element viewed from obliquely below.

FIG. 31 is a schematic perspective view of still yet another example of the illumination device.

FIG. 32A and FIG. 32B are a schematic side view and a schematic plan view, respectively, of the illumination device shown in FIG. 31.

FIG. 33 is a schematic cross-sectional view of the illumination device shown in FIG. 31.

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FIG. 34 is a schematic exploded view of the illumination device showing individual parts.

FIG. 35 is a schematic perspective view of even yet another example of the illumination device.

FIG. 36A is a schematic side view of the illumination device shown in FIG. 35.

FIG. 36B is a schematic plan view of the illumination device shown in FIG. 35.

FIG. 37 is a schematic cross-sectional view of the illumination device shown in FIG. 35.

FIG. 38 is a schematic exploded view of the illumination device in FIG. 35 showing individual parts.

DETAILED DESCRIPTION

FIG. 1 shows an illustrative illumination device suitable for illumination of a quadrangular region. This illumination device 1 includes a projection unit 5 that casts or projects, to a front 19, light (pencil of rays) 3 controlled so as to illuminate a quadrangular or linear region 2 such as a top of a desk, a housing 4 having a quadrangular shape in a plan view and accommodating the projection unit 5, and a driver circuit 8 that operates an LED 6 serving as the light source of the projection unit 5. The projection unit 5 includes an optical device (optical system) 10 including a light-transmissive optical element 11 spreading from a peripheral portion 18 surrounding a central axis (i.e., first axis or Z-axis) 12 to form an arc shape and having a substantially fan-shaped columnar shape, a rod-like shape, or a cylindrical lens shape in a plan view (viewed in the X-Y plane orthogonal to the Z-axis 12). The projection unit 5 also includes the LED 6 that emits source light (first light) 7 to allow the source light 7 to be incident on an end surface of the optical element 11.

The illumination device 1 can be attached to a ceiling 9 to intensively illuminate the quadrangular or linear narrow region 2 such as the top of a desk as shown in FIG. 2. The region to be illuminated is not limited to the top of a desk as long as the region is a quadrangular region or a narrow region and may be a wall, an indoor or outdoor billboard or poster, or the like. The illumination device 1 can intensively illuminate such a quadrangular or narrow region 2. The optical device 10 includes the optical element 11 having a substantially fan shape in a plan view and extending along the first axis 12 serving as the center axis of the fan shape to have a columnar shape, and reflective members 21 and 22 disposed such that the optical element 11 is located between the reflective members 21 and 22.

FIGS. 3A and 3B schematically show the projection unit 5 including the optical device 10. FIG. 3A is a schematic perspective view of the projection unit 5 when viewed from the projection side (front side) 19. FIG. 3B is a schematic perspective view of the projection unit 5 when viewed from the side opposite to the projection side 19. FIG. 4 is a schematic exploded view of the projection unit 5 and the optical device 10.

As shown in FIG. 4, the optical device 10 includes the substantially fan-shaped optical element 11 that spreads at an angle θ (central angle θ or opening angle θ) around the first axis (Z-axis) 12, which is the central axis, when viewed (in a plan view) in a plane (X-Y plane) orthogonal to the Z-axis 12 and that is constituted of a light-transmissive member such as an acrylic resin and glass. In the optical element 11 having a columnar shape extending along the Z-axis 12 as a whole, a space 14 having an opening 13 at an end of the Z-axis 12 (on the bottom surface side or in the negative direction of the Z-axis) exists on an Z-axis 12 side

(inside), and a surface (emission surface) **15** on a projection side (front and outer side) **19** opposite to *Z*-axis **12** side has a substantially arc shape. The optical device **10** further includes the reflective members **21** and **22** arranged such that the optical element **11** is disposed between the reflective members **21** and **22**. The reflective members **21** and **22** have reflective surfaces **23** and **24** facing the optical element **11**. The reflective surface (second reflective surface) **23** and the reflective surface (third reflective surface) **24** are reflective surfaces between which the optical element **11** is disposed, and intersect each other on the *Z*-axis **12**.

As shown in the schematic cross-sectional view of FIG. 5, the optical element **11** is a cylindrical lens having the space **14** along the *Z*-axis **12** inside as a whole and having a multilevel inner surface (transmissive/reflective surface) **16** including transmissive surfaces and reflective surfaces alternately arranged along the *Z*-axis **12** from an opening **13** side of the space **14**. The inner surface **16** of the optical element **11** includes a plurality of fan-shaped transmissive surfaces **32** forming coaxial arcs disposed stepwise from a side opposite to the opening **13** toward the opening **13**, that is, from the positive side toward the negative side of the *Z*-axis **12**; and a plurality of arc-shaped reflective surfaces (first reflective surface) **31** separated from each other via respective ones of the transmissive surfaces **32** and broadening along the *Z*-axis **12** at acute angles with the *X*-*Y* plane. The inner surface **16** of the optical element **11** includes the fan-shaped transmissive surfaces **32** that are arranged sequentially to form coaxial arcs with inner diameters **16r** gradually increasing from the side opposite to the opening **13** toward the opening **13**, that is, from the positive side toward the negative side of the *Z*-axis **12**. In another example, transmissive surfaces may be arranged such that the inside diameters **16r** gradually decrease from the positive side toward the negative side of the *Z*-axis **12**, or a plurality of fan-shaped transmissive surfaces of the same or substantially the same shapes may be arranged to form coaxial arcs.

More specifically, the first reflective surface **31** of the optical element **11** in the present example includes six reflective surfaces (fourth to ninth reflective surfaces) **31a** to **31f** separated from each other via respective ones of six transmissive surfaces (first to sixth transmissive surfaces) **32a** to **32f** perpendicular to the *Z*-axis **12** and parallel to the *X*-*Y* plane from the side (the upper side or the positive direction of the *Z*-axis) opposite to the opening **13** toward the opening **13**, that is, from the positive side toward the negative side of the *Z*-axis **12**. That is, the optical element **11** has the six transmissive surfaces (first to sixth transmissive surfaces) **32a** to **32f** and the six reflective surfaces (fourth to ninth reflective surfaces) **31a** to **31f** alternately arranged from the positive side toward the negative side of the *Z*-axis **12**. The optical element **11** further has an arc-shaped transmissive surface **33** that is closest to the opening **13** and formed around the *Z*-axis **12**.

Accordingly, the optical element **11** has the fan-shaped first transmissive surface **32a**, second transmissive surface **32b**, and third transmissive surface **32c** intermittently arranged along the first axis (*Z*-axis) **12** to have coaxial arc-shape such that the inner diameters **16r** gradually increases from the side opposite to the opening **13** toward the opening **13**; and the arc-shaped fourth reflective surface **31a**, fifth reflective surface **31b**, and sixth reflective surface **31c** respectively arranged on the side opposite to the opening **13** of the first transmissive surface **32a**, the second transmissive surface **32b**, and the third transmissive surface **32c** so as to be inclined at acute angles.

More specifically, the first transmissive surface **32a** farthest from the opening **13** is a fan-shaped transmissive surface centered on the *Z*-axis **12**. The fourth reflective surface **31a** farthest from the opening **13** is arranged to reflect light that has passed through the first transmissive surface **32a** toward an arc-shaped region (first region) with the angle θ of the peripheral portion **18** surrounding the *Z*-axis **12**. The fourth reflective surface **31a** is located on the side opposite to the opening **13** of the first transmissive surface **32a** to form a substantially fan-shaped inverted truncated cone centered on the *Z*-axis **12** inclined relative to the *X*-*Y* plane, and reflects light **7** with an optical axis **7a** parallel to the *Z*-axis **12** toward the direction **19** orthogonal to the *Z*-axis **12**. The fifth reflective surface **31b** is an arc-shaped reflective surface arranged between an inner edge **32b1** of the second transmissive surface **32b** and an outer edge **32a2** of the first transmissive surface **32a** so as to reflect the light **7** that has passed through the second transmissive surface **32b**. The sixth reflective surface **31c** is an arc-shaped reflective surface located between an inner edge **32c1** of the third transmissive surface **32c** and an outer edge **32b2** of the second transmissive surface **32b** so as to reflect the light **7** that has passed through the third transmissive surface **32c**. The seventh reflective surface **31d** and the eighth reflective surface **31e** have substantially the same constitutions with respect to the fourth transmissive surface **32d** and the fifth transmissive surface **32e**.

While the outer surface **15** of the optical element **11** may be a cylindrical surface, the outer surface **15** in the present example is partitioned into seven regions **15a** to **15g** corresponding to the reflective surfaces **31a** to **31f** and the transmissive surface **33** along the *Z*-axis **12**. The regions **15a** to **15g** of the outer surface **15** are optimized as toric free-form surfaces such that light reflected by the reflective surfaces **31a** to **31f** and light transmitted through the transmissive surface **33** are more uniformly emitted.

In the optical device (optical system) **10**, the second reflective surface **23** and the third reflective surface **24** of the reflective members **21** and **22** are attached in contact with lateral surfaces **17a** and **17b** of the optical element **11**, which is a cylindrical lens having a substantially fan shape in a plan view.

As shown in FIG. 3A to FIG. 4, the projection unit **5** of the illumination device **1** includes the optical device **10** and a substrate **6a** attached to the opening **13** of the optical element **11**. The LED **6** is mounted on the substrate **6a**, and an illuminating light **7** travels from the LED **6** in the opening **13** toward the first reflective surface **31** of the space **14** of the optical element **11** along and parallel to the *Z*-axis **12**. The first reflective surface **31** constituted by the separate reflective surfaces **31a** to **31f** are arranged so as to reflect, to the first region with the central angle θ of the peripheral portion **18** surrounding the *Z*-axis **12**, the illuminating light (first light) **7** having a light distribution characteristic with the optical axis **7a** parallel to the *Z*-axis **12**. The optical device **10** includes the first reflective surface **31** and the second and third reflective surfaces **23** and **24**, the second and third reflective surfaces **23** and **24** intersecting each other on the *Z*-axis **12** such that the first reflective surface **31** is disposed between the second and third reflective surfaces **23** and **24**. The second reflective surface **23** reflects the first light **7** at the peripheral portion **18** surrounding the *Z*-axis **12** in the direction of the first reflective surface **31**. The third reflective surface **24** reflects the light **7** from the LED **6** at the peripheral portion **18** surrounding the *Z*-axis **12** in a direction opposite to the direction of reflection by the second reflective surface **23**.

Accordingly, in the optical device **10**, the second reflective surface **23** and the third reflective surface **24** intersecting each other on the Z-axis **12** at the central angle θ reciprocally reflect, in the direction of the arrangement of the first reflective surface **31** in the region with the angle θ , the light **7** emitted from the LED **6** serving as the light source along the Z-axis **12**. The optical device **10** emits light to the region with the angle θ around the Z-axis **12** in a direction perpendicular to the Z-axis **12** by reflection by the first reflective surface **31**.

The second reflective surface **23** and the third reflective surface **24** are disposed to reflect the light **7** from the LED **6** to the region with the angle θ and to be disposed at least near the LED **6**. The reflective surfaces **23** and **24** may intersect the first reflective surface **31**, which allows for efficiently reflecting the light **7** from the LED **6** in the direction of the arrangement of the first reflective surface **31** without leakage.

FIGS. **6A** and **6B** schematically show a situation in which the light (incident light) **7** incident on the optical element **11** of the optical device **10** along the Z-axis **12** is reflected by the first reflective surface **31** and emitted in the direction **19** orthogonal to the Z-axis **12**. As shown in FIG. **6A**, the light **7** emitted from the LED (light source) **6** has a Lambertian light distribution centered on the optical axis **7a**. A component of the light **7** around the optical axis **7a** is reflected by the second reflective surface **23** and the third reflective surface **24** in the direction of the fan-shaped optical element **11** with the central angle θ . As shown in FIG. **6B**, a component of the light **7** in an angle φ of light distribution with respect to the optical axis **7a** is divided by the transmissive surfaces **32a** to **32f** and the separate reflective surfaces **31a** to **31f** of the optical element **11** into a plurality of groups (pencils of rays), and pencils of rays **71** respectively reflected are emitted in the direction **19** orthogonal to the optical axis **7a**. The reflected rays **71** are emitted as the illumination light **3** through the emission surface **15**, which is the outer surface of the optical element **11**. A component of the light **7** emitted from the LED **6** at a large angle φ of light distribution is emitted in the direction **19** orthogonal to the optical axis **7a** through the transmissive surface **33** near the opening **13** of the optical element **11**.

Accordingly, the optical device **10** can convert the light **7** with the Lambertian light distribution into the illumination light **3** with a light distribution appropriate for illumination of a linear or quadrangular region by allowing the first reflective surface **31**, the second reflective surface **23**, and the third reflective surface **24** to reflect the light **7** in the direction **19** orthogonal to the optical axis **7a** so as to form an arc shape. Further, the first reflective surface **31** can convert the light **7** into light traveling in a direction orthogonal to the optical axis **7a** by reflecting the light **7** in the direction **19** orthogonal to the optical axis **7a** to extend a portion sharing a common luminous intensity in the Lambertian light distribution, in which the luminous intensity varies according to the angle φ of light distribution around the optical axis **7a**, from one end to the other end of a linear or quadrangular light distribution. For example, the light (pencil of rays) on the optical axis **7a** with the highest luminous intensity can be extended from one end to the other end of a linear or quadrangular light distribution. Accordingly, a linear or quadrangular light distribution with a more uniform luminous intensity distribution can be obtained by controlling the curvature or inclination of the first reflective surface to control the luminous intensity in the width direction of the linear or quadrangular shape.

FIGS. **7A** and **7B** schematically show examples of the light distribution of the light **3** emitted from the projection unit **5** in the horizontal direction (lateral direction). FIG. **7A** schematically shows an example of the light distribution in the case in which the outer surface **15** of the optical element **11** in a cross section orthogonal to the first axis forms an arc of a circle. FIG. **7B** schematically shows an example of the light distribution in the case in which the outer surface **15** in a cross section orthogonal to the first axis is a free-form surface. Use of the optical device **10** enables the light **7** with the Lambertian light distribution emitted from the LED **6** to be converted into the light **3** with a luminous intensity distribution substantially uniform in the horizontal direction and to be emitted. Optimizing the outer surface **15** using a free-form surface, an aspheric surface, or the like allows for obtaining uniform distribution of the light **3** emitted from the optical device **10**.

FIG. **8** is a schematic cross-sectional view of another example of the illumination device in which at least a portion of the first light that has a light distribution characteristic with the optical axis parallel to the first axis and is incident along the first axis is reflected to the substantially arc-shaped first region around the first axis. A projection unit **5a** of the illumination device **1a** includes an optical device **10a** that has a continuous first reflective surface **31** having a substantially fan shape in a plan view and the second reflective surface (not shown) and the third reflective surface **24**, with the first reflective surface **31** disposed between the second reflective surface and the third reflective surface **24**. Also in the projection unit **5a**, the optical device **10a** can convert the light **7** emitted from the LED **6** in the direction of the Z-axis **12** into light in the direction **19** orthogonal to the Z-axis **12**, and the light converted into the light **3** with a luminous intensity substantially uniform in the horizontal direction can be emitted.

On the other hand, in the optical device **10a** of the projection unit **5a**, employing the continuous first reflective surface **31** increases the region occupied by the first reflective surface **31**, which leads to increase in size of the device. On the contrary, in the optical device **10** including the cylindrical optical element **11**, the first reflective surface **31** is provided as a plurality of total-reflection surfaces **31a** to **31f** separate from one another inside the cylindrical lens, like a Fresnel lens. That is, the optical device **10** has the reflective surfaces **31a** to **31f** that are separated from one another in the direction along the Z-axis (first axis) **12** and reflect the light (first light) **7** from the LED **6** to the direction **19** orthogonal to the Z-axis **12** at the peripheral portion **18** surrounding the Z-axis **12**. Further, the optical device **10** includes the optical element **11** that has a fan shape in a cross section perpendicular to the Z-axis (first axis) **12**, has the reflective surfaces **31a** to **31f** inside, and has the multilevel inner surface **16** including the reflective surfaces **31a** to **31f** and the transmissive surfaces **32a** to **32f** respectively corresponding to the reflective surfaces **31a** to **31f**.

Accordingly, the compact optical device **10** and the compact illumination device **1** employing the same can be provided. Further, the optical element **11** has the reflective surfaces **31a** to **31f** and the corresponding regions (emission surfaces) **15a** to **15f** of the outer surface **15**. With this structure, the reflective surfaces and the emission surfaces can be optimized for light reflected or transmitted by these surfaces, which allows for obtaining the optical device **10** that converts light into the light **3** with an even more uniform luminous intensity distribution in the horizontal direction and emits the light.

Each of the emission surfaces **15a** to **15f** corresponding to the reflective surfaces **31a** to **31f** of the optical element **11** is generally a toric surface including a portion curved in a cross section in the direction along the *Z*-axis **12**. Further, the emission surfaces **15a** to **15f** can have any appropriate design and each of the emission surfaces **15a** to **15f** may include a portion that is noncircular in a cross section perpendicular to the *Z*-axis **12**.

As described above, the optical element **11** of the optical device **10** has at least one first reflective surface **31** inside that reflects, to the substantially arc-shaped first region with the angle θ around the first axis **12**, at least a portion of the first light **7** having a light distribution characteristic with the optical axis **7a** parallel to the first axis **12** incident along the first axis (*Z*-axis) **12**. More specifically, the optical element **11** has the reflective surfaces (reflective arc surfaces) **31a** to **31f** that function as the first reflective surface **31** and are separated in the direction along the first axis **12** and the light-transmissive outer surface (emission surface) **15** that refracts at least a portion of the rays **71** reflected by the reflective arc surfaces **31a** to **31f** and emits the light as the illumination light **3** around the first axis **12**. Accordingly, the optical element **11** has the first reflective surface **31** that converts the direction of travel (optical axis) of the first light **7** with the optical axis **7a** parallel to the first axis **12** into a direction different from the first axis **12**, that is, a direction orthogonal to the first axis **12** in the above example, and the emission surface **15** functioning as a refracting surface (lens) that converts the optical axis and/or the light distribution as the illumination light **3** by refracting and emitting the reflected rays **71**. Thus, compared with the optical device **1a** that controls the distribution of the illumination light **3** using only the reflective surface **31** as shown in FIG. **8**, the optical device **10** includes two factors controlling the direction of emission and/or the light distribution of the illumination light **3**, which facilitates control of the divergence and distribution of the illumination light **3**, and the illumination light **3** having a more uniform light distribution is easily emitted.

In the optical element **11** described above, a plurality of total internal reflection (TIR) prisms respectively having the arc surfaces **31a** to **31f** constituting the first reflective surface **31** and the transmissive surfaces **32a** to **32f** in combination are arranged for the inner surface **16**, and the outer surface **15** includes the emission surfaces **15a** to **15f** corresponding to the arc surfaces **31a** to **31f**, so that the first reflective surface **31** and the outer surface **15** functioning as a refracting surface are integrated. It is also easy to constitute toric surfaces by dividing the outer surface **15** into the emission surfaces **15a** to **15f** corresponding to the arc surfaces **31a** to **31f** serving as TIR lens surfaces and to introduce a surface for controlling the light distribution around the *Z*-axis **12**, and the illumination light **3** having a more uniform light distribution can be emitted.

The optical device **10** includes the optical element **11** that controls the direction and divergence of the illumination light **3** constituted of the first light **7**, and the second reflective surface **23** and the third reflective surface **24** intersecting each other on the first axis (*Z*-axis) **12** with the optical element **11** having the first reflective surface **31** disposed between the second reflective surface **23** and the third reflective surface **24**. With this structure, the first light **7** having a divergence of 360° (directions of the whole circumference) can be condensed (reflected) onto a region in which the first light **7** can be processed by the first reflective surface **31** of the optical element **11**, so that the light **7**

emitted from the LED **6**, which is the light source, can be efficiently emitted as the illumination light **3** in a desired direction and region.

FIG. **9A** schematically shows an example of the light **3** emitted from the illumination device **1** including the projection unit **5** and projected on a screen. As shown in FIG. **9B**, a plurality of light leakages **81** to **84** were found above and below the quadrangular illuminated region **2**. According to experiments by the present inventors, it has been found that the arc-shaped light leakages **81** to **83** are attributable to stray light produced by surface reflection by the transmissive surface **33** and the emission surface **15g** on the lowermost layer of the optical element **11**. The optical element **11** has the surface that transmits a portion of the light **7** in the direction **19** orthogonal to the *Z*-axis **12** in the lowermost portion closest to the incident side of the multilevel inner surface **16** so as to allow emission, in the direction **19** orthogonal to the *Z*-axis **12**, of a component at the largest angle φ of light distribution of the light **7** with the Lambertian light distribution. Accordingly, the arc-shaped light leakages **81** to **83** can be reduced by anti-reflection-coating or diffusing, such as graining, at least one of the inner surface **33** and the outer surface (emission surface) **15g** in the lowermost portion of the light-transmissive optical element **11**.

According to experiments by the present inventors, it has been found that the horn-like shape light leakages **84** are attributable to the inner surface reflection by the lateral surfaces **17a** and **17b** of the optical element **11**. Accordingly, with anti-transmission processing or diffusing processing on the lateral surfaces **17a** and **17b** on both sides of the optical element **11** in a direction around the *Z*-axis **12**, the light leakages **84** can be reduced. More specifically, coloring the lateral surfaces **17a** and **17b** black or providing irregularities on the lateral surfaces **17a** and **17b** allows for reducing the light leakages **84**.

FIG. **10** schematically shows an example of the light **3** emitted from the illumination device **1** including the optical element **11** with the configuration described above and cast on a screen. Light leakages were hardly observed, and it has been found that light leakages are reduced by the configuration as described above.

FIG. **11A** schematically shows illustrative stray light **85** that may appear around the illumination device **1**, for example, on the ceiling **9**. It is thought that the stray light **85** is attributable to light reflected by the reflective surfaces **31** and the transmissive surfaces **32** in the inner surface **16** of the optical element **11**.

FIG. **12** schematically shows still another example of the illumination device **1b**. The illumination device **1b** includes a plurality of louvers (shielding plates) **90** on the boundaries between the layers (regions) **15a** to **15g** in a front side **19** of the outer surface (emission surface) **15** of the optical element **11** of the illumination device **1** described above. The louvers **90** are plate-like members extending parallel to the direction of emission, that is, parallel to the *X*-*Y* plane, toward the front side **19** from the outer surface **15** of the optical element **11**. As shown in FIG. **11B**, the stray light **85** was hardly observed in the case of the illumination device **1b** provided with the louvers **90**.

The louvers **90** can further collimate the illumination light **3** emitted from the outer surface **15** of the optical element **11** and reduce the effect of divergent rays produced by stray light inside the optical element **11**. A plurality of louvers **90** are distributed in the *Z*-axis direction such that each of the louvers **90** corresponds to a respective one of the layers **15a** to **15g** in the illumination device **1b**, but each of the louvers

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90 may be disposed for corresponding two or more of the layers 15a to 15g or disposed at predetermined intervals in the Z-axis direction regardless of the layers 15a to 15g. The intervals between the louvers 90 and the amounts (lengths) of projection of the louvers 90 from the outer surface 15 of the optical element 11 can be determined by the degree of parallelism of the illumination light 3 required to illuminate the illuminated region 2, the intensity and divergence (angle) of the divergent rays, which constitutes stray light, from the outer surface 15 of the optical element 11, and the like. For example, the length of a louver 90 is approximately equal to the radius (distance from the optical axis to the outer surface) of the optical element 11. In the case in which the intervals between the louvers 90 are excessively short, luminance unevenness is likely to be caused in the illuminated region. In the case in which the intervals between the louvers 90 are excessively long, such as the case in which the louvers 90 are installed only at the top and the bottom, it is difficult to inhibit the effect of stray light. Accordingly, in a preferable example, the louvers 90 are disposed at the intervals of the layers 15a to 15g.

As described above, the illumination device 1 includes the lens (which may be referred to as a refractor, a transmissive member, or the optical element) 11 having the shape of a body of revolution, the optical element 11 has the shape of a fan-shaped cylindrical column defining a recess (i.e., a partial cylindrical column or body of revolution defining an angular recess). The space 14, surrounded by surfaces parallel to the lateral surfaces 17a and 17b of the optical element 11 and the incident surface (opening) 13 of the optical element 11, is defined by the reflective surfaces 23 and 24 as the surfaces parallel to the lateral surfaces 17a and 17b. The LED 6 serving as the light source is disposed inward of the intersection (Z-axis) 12 of the reflective surfaces 23 and 24. The LED 6 serving as the light source is therefore disposed offset from the rotation axis (central axis or Z-axis) 12 inside the optical element 11 having the shape of a cylindrical column. However, the light 7 from the LED 6 is subjected to reflection by the reflective surfaces 23 and 24, and the light 3 is emitted from the optical element 11 as if the light source is located on the Z-axis 12.

The optical element 11 has the arc-shaped emission surfaces 15a to 15g. The optical element 11 also has the transmissive portion (curved inner wall) 33 on the bottom surface side (opening 13 side) of the inside (inner surface) 16 and the total internal reflection surfaces 31a to 31f on the upper surface side (optical axis direction or the side opposite to the opening 13). The total internal reflection surfaces 31a to 31f are inclined inner walls that causes total internal reflection and emit the illumination light 3 matched in the same direction perpendicular to the Z-axis 12 and the optical axis 7a at the peripheral portion 18 surrounding the Z-axis 12. The arc-shaped emission surfaces 15a to 15g of the optical element 11 include curved surfaces having the function of lenses. Accordingly, in a cross section of the optical element 11 in the direction along the optical axis direction 7a, the total internal reflection surfaces 31a to 31f of the reflective portions have straight lines or curved surfaces, and the emission surfaces 15a to 15g also have straight lines or curved surfaces.

With this structure, the optical device 10 efficiently and more uniformly converts the light 7 from the light source (LED) 6 into light with a linear or quadrangular light distribution. Accordingly, the illumination device 1 that can more uniformly and brightly illuminate a linear or quadrangular region can be provided using the optical device 10.

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FIG. 13A is a schematic lateral view of yet another illumination device 1c. FIG. 13B is a schematic top view of the illumination device 1c. FIG. 14 schematically shows an exploded view of the illumination device 1c. FIG. 15 is a schematic cross-sectional view of the schematic structure of the illumination device 1c taken along the line XV-XV (see FIG. 13B) along the center of the illumination device 1c. Further, FIG. 16 schematically shows emission of the illumination light 3 from the illumination device 1c. The illumination device 1c includes the optical device 10 configured to convert the light (first light) 7 from the LED 6 serving as the light source into the illumination light 3 and emits the light, and the substrate 6a on which the LED 6 that emits the first light 7 has been mounted. The optical device 10 has the first reflective surface 31 configured to reflect, to the substantially arc-shaped first region with the angle θ around the first axis 12, at least a portion of the first light 7 incident along the first axis (Z-axis) 12 and having a light distribution characteristic with the optical axis 7a parallel to the first axis 12, the second reflective surface 23 and the third reflective surface 24 that intersect each other on the first axis 12 with the first reflective surface 31 located between the second reflective surface 23 and the third reflective surface 24, and the light-transmissive emission surface 15 adapted to refract at least a portion of the rays 71 reflected by the first reflective surface 31 to emit the rays around the first axis 12.

More specifically, the optical device 10 includes a bent mirror 20 in which the first reflective member 21, having the second reflective surface 23, and the second reflective member 22, having the third reflective surface 24, intersect each other on the first axis 12 at the angle θ , and the light-transmissive optical element 11 having the inner surface 16 including the first reflective surface 31 and the emission surface 15 that serves as the outer surface. The first reflective surface 31 includes the reflective arc surfaces 31a to 31d separated in the direction along the first axis 12, and the light-transmissive emission surfaces 15 that refract at least a portion of the rays 71 reflected by the reflective arc surfaces 31a to 31d and emit the light around the first axis 12 have periodic irregularities 40 in a cross section in the direction along the first axis 12. The optical element 11 further has the transmissive surface 33 that transmits the first light 7 on the incident side (lowermost portion) of the first light 7 in the inner surface 16. The transmissive surface 33 refracts and guides a wide-angle (peripheral) component of the first light 7 to the emission surface 15. The emission surface 15 also includes a portion (region) that emits light (light in a direction substantially orthogonal to the first axis 12 in the present example) 72 the direction of which has been changed by refraction with respect to the first axis 12 as the illumination light 3, and the periodic irregularities 40 are formed throughout the entire emission surface 15 in the direction along the Z-axis 12.

The periodic irregularities 40 in the direction along the first axis (Z-axis) 12 include recesses 41 and protrusions 42 repeated at a predetermined pitch in the Z-axis direction. The irregularities 40 may form the shape of a sine wave, a zigzag in which a straight line is bent many times into the Z shape, or a combination of straight lines and curved lines. The recesses 41 and the protrusions 42 alternately and repeatedly appear. The amplitude, which is the distance (width) between a peak and a valley of the irregularities 40, and the pitch (period) of repetition of the periodic irregularities 40 may be constant in the direction of the Z-axis 12 or may vary in the direction of the Z-axis 12 according to a predetermined function. The amplitude and the period of the periodic irregularities 40 may be constant in the direction

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(circumferential direction, i.e., θ direction) around the Z-axis 12 or may vary in the θ direction according to a predetermined function. The emission surface 15 may have periodic irregularities in the circumferential direction.

The light-transmissive emission surface 15 may have a plurality of inflection points 45 at predetermined intervals in a cross section in the direction along the first axis 12. Each of the inflection points 45 may be at least one of a location at which the surface changes from a protrusion 42 to a recess 41 or from a recess 41 to a protrusion 42, a location at which the surface changes from a curved line to a straight line or from a straight line to a curved line, and a location at which the inclination direction of a straight line changes.

The emission surface 15 having the periodic irregularities 40 and/or the inflection points 45 at predetermined intervals has an effect on the emitted illumination light 3 to obtain more uniform intensity distribution (luminous intensity distribution) of the illumination light 3 in the vertical direction. The period of the periodic irregularities 40 or the intervals between the inflection points 45 may or may not correspond to the reflective surfaces 31a to 31d and the transmissive surface 33 of the optical element 11. To facilitate obtaining the effect of uniform intensity distribution, there may be at least one periodic irregularity 40 in the regions 15a to 15d of the outer circumferential surface (emission surface) 15 respectively facing the reflective arc surfaces 31a to 31d and in the region 15g corresponding to the transmissive surface 33. The periodic irregularities 40 may include a plurality of recesses 41 or protrusions 42 in the regions 15a to 15d and 15g respectively facing the reflective arc surfaces 31a to 31d and the transmissive surface 33. The rays 71 reflected by each of the reflective surfaces 31a to 31d are incident on the emission surface having two or more recesses 41 and/or protrusions 42 on the outer surface 15. The number of irregularities corresponding to each of the reflective surfaces 31a to 31d may be appropriately selected. Selecting the period (pitch) such that at least one combination of the recess 41 and the protrusion 42 corresponds to each of the reflective surfaces 31a to 31d enables designs of the emission surface 15, which is the outer surface of the optical element 11, and the number (number of levels) of the reflective surfaces 31 constituting the inner surface 16 to be separately developed, so that design flexibility of the optical element 11 is increased.

Similarly, the regions 15a to 15d of the emission surface 15 respectively facing the reflective arc surfaces 31a to 31d may have at least two inflection points 45 in a cross section in the direction along the first axis 12. This is similar for the region 15g corresponding to the transmissive surface 33. If each of the regions 15a to 15d and 15g of the outer circumferential surface 15 has at least two inflection points 45, each region has at least a shape changing from concave to convex and from convex to concave or a shape changing from convex to concave and from concave to convex. Accordingly, the rays 71 that have reached the outer surface 15 alternately converge and diverge instead of being converted into parallel rays in the direction along the first axis 12 on the outer surface 15. When the rays reach the illuminated region 2, a portion of the illuminated region 2 is illuminated with the illumination light 3 emitted through the various regions 15a to 15d and 15g of the emission surface 15, and the intensity distribution (luminance distribution) of illumination becomes uniform.

FIG. 16 schematically shows general travel of rays of light through the optical element 11 having the shape of a sine wave along the Z-axis 12 as the periodic irregularities 40 as an example. Among the irregularities 40, the recesses

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41 function as concave lenses to allow light to diverge, and the protrusions 42 function as convex lenses to allow light to converge. Accordingly, light reflected by the reflective surfaces 31a to 31d and emitted from the outer surface 15 has alternate regions of convergence and divergence. Rays reflected by one reflective surface toward the emission surface follow different optical paths of convergence and divergence, so that the quality of the illumination unevenness can be improved.

The emission surface 15 may include a portion that controls the light distribution of the illumination light 3 emitted through the emission surface 15 around the first axis 12, that is, a portion in which the period or amplitude of the periodic irregularities or the positions or intervals of inflection points change around the Z-axis. The shape of the outer surface 15 of the optical element 11 may be selected according to the position at the angle θ around the Z-axis to further control the light distribution in the Z-axis direction (vertical direction) at each location in the horizontal direction (X-Y plane) orthogonal to the Z-axis 12. As shown in FIG. 13B and FIG. 14, the optical element 11 of the illumination device 1c has the periodic irregularities 40 designed so that the light distributions at each of locations at angles $\theta 1$ of 0° , 15° , 30° , and 45° with respect to the center $\theta 0$ in a plan view of a plane (X-Y plane) orthogonal to the Z-axis 12 will be uniform in the vertical direction (Z-axis direction). Accordingly, the optical element 11 may have portions (regions) 15x having a different amplitude and/or period of the periodic irregularities 40 of the emission surface 15 at angles $\theta 1$ of 0° , 15° , 30° , and 45° . Portions of the emission surface 15 between locations at these angles can be designed such that irregularities 40 of adjacent cross sections are connected to form a seamless surface.

Basically, the emission surface 15 of the optical element 11 can be designed irrespective of the shape of the inner surface 16 including the TIR prisms 39. Accordingly, the design of the emission surface 15, which is the outer surface, can be changed without changing the design of the inner surface 16. Thus, the optical element 11 that can appropriately control the light distribution in the vertical direction according to the distance from the illuminated region 2 or the like to obtain the luminance distribution in the longitudinal direction (horizontal direction) in the illuminated region 2 can be obtained. The emission surface 15 may be designed to be symmetric about the center $\theta 0$ in the horizontal direction (opening angle $\theta 1$) or may be designed to be asymmetric regarding the illuminated region 2.

In the optical element 11, the inner surface 16 includes the reflective arc surfaces 31a to 31d, each including concentric arc-shaped reflective surfaces (total internal reflection surfaces) centered on the first axis 12, and also includes the transmissive surfaces 32a to 32d respectively corresponding to the reflective surfaces 31a to 31d. Accordingly, the inner surface 16 of the optical element 11 includes the multilevel TIR (total internal reflection) prisms 39.

The optical device 10 further includes a control member 79 that prevents the component of the first light 7 on the optical axis 7a from being directly incident on the first reflective surface 31. The control member may be a control member that shields (absorbs) light or may be a control member that reflects or diffuses light. The optical device 10 in the present example includes a fan-shaped light-shielding or nonreflective control member 79 protruding from the first axis 12 at the top of the bent mirror 20 along the first axis 12. The control member 79 absorbs a portion, such as a component with an elevation $\varphi 1$ (elevation in a range of 80° to 90°), of the first light 7 from the LED 6 around the optical

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axis $7a$ to so that the component with an elevation φ_1 is not incident on the optical element **11**. The control member **79** may have a mirror surface or scattering surface having the shape of an inverted cone extending along the first axis **12**, or may be configured to appropriately allow the component with the elevation φ_0 to be incident on the optical element **11**.

FIG. **17** is a graph showing the incidence efficiency of light incident on the reflective surfaces **31** along the Z-axis (first axis) **12** according to the elevation φ . The incidence efficiency is 97% at an elevation φ of 80° . Accordingly, it can be understood that the optical loss is about 3% even if light in the range of elevations φ of 80° to 90° , that is, at such elevations φ_1 that the light travels directly upward from the LED **6**, is not incident.

On the other hand, as indicated by the dashed lines in FIG. **16**, the volume required to form a reflective surface **31x** that reflects light including light at elevations of 80° to 90° to another angle, such as a direction perpendicular to the Z-axis **12**, with respect to the Z-axis **12** corresponds to about 15% of the total volume of the optical element **11**. As shown in FIG. **16**, in the optical element **11** of the present example, the surface **31a** that reflects light except for light at elevations φ of 80° to 90° (elevation φ_1) is employed instead of the reflective surface **31x** including a surface that reflects light at the elevation φ_1 , which allows reduction in thickness and size. Accordingly, with this optical element **11**, the compact optical device **10** and illumination device **1c** in which the efficiency of conversion of the light from the LED **6** into the illumination light **3** hardly decreases can be provided.

As described above, the optical element **11** includes the first reflective surface **31** that reflects the first light **7** emitted from the LED **6** and having the Lambertian light distribution at an angle different from the angle of the optical axis $7a$ of the first light **7**, generally in a direction orthogonal to the optical axis $7a$, to a predetermined region (first region) with the angle θ around the optical axis $7a$ to control the intensity distribution of light; and the cylindrical or arc-shaped emission surface **15** that can be designed irrespective of the reflective surfaces **31** and that refracts and emits the reflected rays **71** to emit the illumination light **3** having a shape and intensity distribution that agree with the illuminated region **2**. Further, providing the periodic irregularities **40** in the longitudinal direction (vertical direction) on the cylindrical or arc-shaped emission surface **15** allows for controlling the divergence and intensity distribution of the illumination light **3** in the vertical direction (Z direction). Also, adjusting the shape of the emission surface **15** in the circumferential direction allows for controlling the divergence and intensity distribution in the circumferential direction (horizontal direction or XY direction). Accordingly, the optical device **10** and the illumination device **1** including this optical element **11** can emit the illumination light **3** that can more uniformly illuminate the entire regions **2** having various regions, shapes, or constitutions.

FIG. **18A** to FIG. **21C** schematically show several examples of the optical element **11** for the illumination device appropriate for regions **2** having various shapes or constitutions. The optical element **11** shown in FIGS. **18A** and **18B** emits illumination light **3** with a normal divergence, what is called a medium light distribution, in the horizontal direction. As shown in FIG. **18A**, the outer surface (emission surface) **15** of the optical element **11** has the arc shape extending around the first axis **12** at the center. As shown in the schematic cross-sectional view of FIG. **18B**, the emission surface **15** of the optical element **11** has the periodic

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irregularities **40** for controlling the divergence of the illumination light **3** in the vertical direction along the first axis **12**.

The optical element **11** shown in FIGS. **19A** to **19C** is an example of the optical element **11** that emits illumination light **3** with a medium light distribution or divergence in the horizontal direction while having a wide divergence in the vertical direction along the first axis **12**. As shown in FIG. **19A**, the outer surface (emission surface) **15** of the optical element **11** has an arc shape extending around the first axis **12** at the center. As shown in the schematic cross-sectional view of FIG. **19B**, the amplitude (such as the distance, height, or sag between the peak of a protrusion **42** and the bottom of a recess **41**) of the periodic irregularities **40** on the emission surface **15** of the optical element **11** may be larger than the amplitude of the irregularities **40** shown in FIG. **18B**. The periodic irregularities **40** may be a collection of curved surfaces like a sine wave as shown in FIG. **19B** or may be a collection of straight lines (slopes) at different angles like a zigzag as shown in FIG. **19C**.

The optical element **11** shown in FIG. **20A** is an example suitable for illumination of a region **2** that is narrow in the horizontal direction. The emission surface **15** of the optical element **11** has a shape, such as a surface with a large curvature (small curvature radius), appropriate for emitting illumination light **3** with a narrow light distribution. The optical element **11** shown in FIG. **20B** is an example appropriate for illumination of a region **2** that is large (long) in the horizontal direction. For example, the light distribution angle is increased by providing one or more irregularities also in the circumferential direction. As shown in FIG. **20B**, the emission surface **15** can be designed to be recessed at an opening angle of 0° and to be protruded on both sides in a cross section (cross section in the horizontal direction or in a plan view) in a direction perpendicular to the first axis **12**. The optical element **11** having the emission surface **15** having a bifoliate or protruded-recessed-protruded shape in a cross section in the horizontal direction is appropriate for emitting illumination light **3** with a broad light distribution for illuminating the region **2** that is long in the horizontal direction. The optical element **11** shown in FIG. **20C** is an example suitable for illumination of a linear region **2** extending in the circumferential direction on the inner surface of a cylindrical column.

The optical element **11** shown in FIG. **21A** is an example appropriate for illumination of a three-dimensional surface (region) **2** constituted of a plurality of linear surfaces combined into a U-like shape. The emission surface **15** of the optical element **11** includes, in a cross section in a direction perpendicular to the first axis **12**, a portion **15y** that forms a straight line or a curved line convex or concave with a large curvature radius at the position at an opening angle of 0° facing the center of the U-like shape; and recessed portions **15z** corresponding to positions of the U-like shape bent at a right angle. Employing such a shape of the emission surface **15** enables provision of the optical element **11** appropriate for linear and uniform illumination of the U-shaped inner wall.

The optical element **11** shown in FIG. **21B** is an example appropriate for illumination of a three-dimensional surface (region) **2** constituted of a plurality of linear surfaces combined into a V shape. The emission surface **15** of the optical element **11** has, in a cross section in a direction perpendicular to the first axis **12**, a convex portion **15z** convex toward a portion corresponding to the position at which the surfaces intersect each other to form a V shape. Employing such a shape of the emission surface **15** enables provision of the

optical element **11** appropriate for linear and uniform illumination of the V-shaped inner wall.

The optical element **11** shown in FIG. **21C** is an example appropriate for illumination of a three-dimensional surface (region) **2** constituted of a plurality of linear surfaces asymmetrically combined into an L shape. The emission surface **15** of the optical element **11** has, in a cross section in a direction perpendicular to the first axis **12**, a protruding portion **15z** protrudes toward a portion corresponding to the position at which the surfaces intersect each other to form the L shape. Employing such an asymmetric shape of the emission surface **15** around the first axis **12** enables provision of the optical element **11** appropriate for linear and uniform illumination of the L-shaped inner wall.

Controlling the shape of the emission surface (outer surface) **15** in a cross section in a direction along the first axis **12** and the shape of the emission surface **15** in a cross section in a direction perpendicular to the first axis **12** as described above allows for emitting the illumination light **3** having different light distribution characteristics. Thus, the illumination device **1** including the optical element **11** having the emission surface **15** can more uniformly illuminate linear illuminated regions **2** with various constitutions.

FIG. **22** schematically shows an illumination device **1d**, which is even another example of the illumination device. FIG. **23** schematically shows the illumination device **1d** without illustration of a radiating fin **59** that has been attached, and FIG. **24** schematically shows the illumination device **1** disassembled into constituents. The illumination device **1d** is one example of a modular lighting tool and includes a light-shielding mask **51** covering the periphery of the emission surface **15** constituting the front surface (outer surface) of the optical element **11**. The light-shielding mask **51** covering the periphery of the emission surface **15** outside the emission surface **15** has the function of reducing glare and stray light. The illumination device **1** includes the optical element **11** having the first reflective surface **31** in the inner surface **16**, the bent mirror (sheet-metal mirror) **20** having the second reflective surface **23** and the third reflective surface **24** between which the inner surface **16** of the optical element **11** is located, the quadrangular flared light-shielding mask **51** covering the periphery of the emission surface **15** of the optical element **11**, resin casings **52**, **53**, and **54** used for assembling the optical element **11**, the sheet-metal mirror **20**, and the mask **51**, the substrate **6a** on which the LED **6** serving as the light source has been mounted, and a sheet-metal heat spreader **58** that supports the substrate **6a** and transfers heat from the LED **6** to the radiating fin **59**.

FIG. **25A** is a schematic side view of an illumination device **1e**, which is further another example of the illumination device. FIG. **25B** is a schematic top view of the illumination device **1e**. FIG. **26** schematically shows an exploded view of the illumination device **1e**. FIG. **27** is a schematic cross-sectional view of the schematic structure of the illumination device **1e** taken along the line XXVII-XXVII (see FIG. **25B**) along the center of the illumination device **1e**. The illumination device **1e** includes the optical device **10** that converts the light (first light) **7** from the LED **6** serving as the light source into the illumination light **3** and emits the light, and the substrate **6a** on which the LED **6** that emits the first light **7** has been mounted. The optical device **10** has the first reflective surface **31** disposed to reflect at least a portion of the first light **7** incident along the first axis (Z-axis) **12** and having a Lambertian light distribution with the optical axis **7a** parallel to the first axis **12** toward a substantially arc-shaped first region with the angle θ around

the first axis **12** to obtain substantially collimated rays **71** in a direction perpendicular to the optical axis **7a** (first axis (Z-axis) **12**); the second reflective surface **23** and the third reflective surface **24** intersecting each other on the first axis **12** with the first reflective surface **31** located between the second reflective surface **23** and the third reflective surface **24**; the light-transmissive emission surface **15** adapted to refract at least a portion of the rays **71** reflected by the first reflective surface **31** to emit the rays around the first axis **12**; and a plurality of light-shielding louvers **90** protruded from the emission surface **15**.

The constitution of the optical device **10** is substantially the same as in the above example except that the louvers **90** are included, and the optical device **10** includes the bent mirror **20** having the second reflective surface **23** and the third reflective surface **24** and the light-transmissive optical element **11** including the first reflective surface **31** in the inner surface **16** and the emission surface **15** serving as the outer surface. The optical element **11** has the multilevel inner surface **16** including the reflective arc surfaces **31a** to **31d** and the transmissive surfaces **32a** to **32d** respectively corresponding to the reflective arc surfaces **31a** to **31d** inside the optical element **11**, and has the emission surface **15** having the periodic irregularities **40** and/or a plurality of inflection points **45** at an outer region of the optical element **11**. The optical element **11** is a substantially fan-shaped light-transmissive member with an angle θ of 180° or less or less than 180° around the first axis **12** in a cross section perpendicular to the first axis **12**. The reflective arc surfaces **31a** to **31d** and the transmissive surfaces **32a** to **32d** respectively corresponding to the reflective arc surfaces **31a** to **31d** constitute the total internal reflection (TIR) prisms **39**, and the multiple TIR prisms **39** are arranged along the first axis **12** to constitute the inner surface **16** of the optical element **11**.

FIG. **28** schematically shows the optical element **11**. FIG. **29** is a schematic side exploded view, and FIGS. **30A** to **30C** are schematic perspective exploded view of the optical element **11**, showing a plurality of light-transmissive members **111a** to **111e**, which may be referred to as "parts **111a** to **111e**". FIG. **30A** is a schematic exploded view of the optical element **11** as viewed from the emission surface (outer surface) **15** side. FIG. **30B** is taken from the upper side of the inner surface **16**, that is, from the side opposite to the incident side of the first axis (Z-axis) **12** from which the first light **7** enters. FIG. **30C** is taken from the lower side of the inner surface **16**, that is, from the incident side of the first axis **12**.

Each of the light-transmissive members (parts) **111a** to **111e** has an end surface **115** perpendicular to the first axis (Z-axis) **12**, and the optical element **11** includes an assembly **110** in which the parts **111a** to **111e** are layered along the first axis **12**. The optical element **11** is divided into the parts **111a** to **111e** along the X-Y plane along the Z-axis **12** at respective positions of the concentric arc-shaped fan-shaped transmissive surfaces **32a** to **32d** disposed stepwise. The assembly **110** includes the four parts **111a** to **111d** having substantially a fan-shape in a plan view, each of the four parts **111a** to **111d** including a single TIR prism **39** (single TIR prism) having a corresponding one of the transmissive surfaces **32a** to **32d** and a corresponding one of the reflective surfaces (reflective curved surfaces or reflective arc surfaces) **31a** to **31d** in a corresponding inner surface **16**, and a single part **111e** having a substantially fan shape in a plan view and having the transmissive portion **33** in a corresponding inner surface **16** without having the reflective surface. Each of the parts **111a** to **111e** has, at an outer surface **15**, a structure

constituting a corresponding portion of the periodic irregularities **40** constituting the outer surface **15** of the optical element **11** and respectively correspond to the reflective surfaces **31a** to **31d** and the transmissive portion **33** of the inner surface **16**.

Each of the light-transmissive parts **111a** to **111d** includes at least one combination of a corresponding one of the reflective curved surfaces **31a** to **31d** functioning as the first reflective surface **31** and a corresponding one of the transmissive surfaces **32a** to **32d**, that is, at least one TIR prism **39**. Each of the parts **111a** to **111d** may include a plurality of TIR prisms **39**. Each of the parts **111a** to **111d** may have a corresponding one of the reflective curved surfaces **31a** to **31d** and a corresponding one of the transmissive surfaces **32a** to **32d** so as to include a single TIR prism **39**. The TIR prisms **39** project toward the inner surface **16** of the optical element **11**. When the optical element **11** has an arc shape, a plurality of TIR prisms **39** can be disposed. On the other hand, when the optical element **11** has a cylindrical or annular optical element as described in the example below, it is difficult to disposed a plurality of TIR prisms **39** in the inner surface, but having a structure separated into parts for respective ones of the TIR prisms **39** in the direction of the Z-axis **12** allows for easily manufacturing an optical element including a plurality of TIR prisms **39** inside the optical element.

The TIR prisms **39** constituting the inner surface **16** of the optical element **11** have the function of collimating the light **7** from the LED **6** incident along the Z-axis **12** toward a direction perpendicular to the Z-axis **12**, but stray light may be produced inside a light-transmissive seamless optical element **11**.

If stray light is emitted from the emission surface **15** of the optical element **11** and recognized at the outside, unintended regions may be illuminated, or glare may be caused when the stray light has entered the eye. With the optical element **11** having a structure in which the parts separated in the direction of the Z-axis **12** for respective TIR prisms **39** are assembled, the advantage of reducing generation of stray light for respective TIR prisms **39** can be obtained.

To prevent stray light produced in each of the parts **111a** to **111e** from being emitted through other ones of the parts **111a** to **111e**, the assembly **110** may include light-shielding members disposed between at least a portion of the parts **111a** to **111e**. Alternatively, at least a portion of the end surfaces **115** of the parts **111a** to **111e** perpendicular to the Z-axis **12** may be light-shielding surfaces, or these structures may be combined.

The assembly **110** constituting the optical element **11** in the present example includes the louvers **90** that are light-shielding members at least partially disposed between the respective light-transmissive parts **111a** to **111e**. The louvers **90** include portions **91** extending (protruding) from the emission surface **15** of the optical element **11** to shield stray light emitted from the emission surface **15** and portions **92** sandwiched between the parts **111a** to **111e** to shield stray light between the parts.

The assembly **110** includes the parts **111a** to **111e** having light-shielding regions **117** in at least a portion of the end surfaces **115**. The light-shielding regions (portions) **117** may be formed when the parts **111a** to **111e** are shaped by a technique such as two-color molding, or desired portions may be treated such that the light-shielding property is imparted after the parts **111a** to **111e** are shaped.

Each of the parts **111a** to **111e** has joining portions on an end side of the outer surface **15** for stacking the parts **111a** to **111e**. More specifically, the uppermost part **111a** has a

recess structure **119** in a lower end surface of the uppermost part **111a**, each of the intermediate parts **111b** to **111d** has a protruding structure **118** on an upper end surface **115** of each of the intermediate parts **111b** to **111d** and a recess structure **119** in a lower end surface of each of the intermediate parts **111b** to **111d**, and the lowermost part **111e** has a protruding structure **118** on an upper end surface **115** of the lowermost part **111e**. The protruding structures **118** and the recess structures **119** are engaged with each other via through-holes **98** of the louvers, each disposed between a respective one of the protruding structures **118** and a respective one of the recess structures **119**, so as to constitute the assembly **110** including the parts **111a** to **111e**. Any appropriate configuration other than using the parts **111a** to **111e** may constitute the assembly **110**. For example, a structure in which the structure described above is turned upside down may be employed, an adhesive or the like may be used, or the parts **111a** to **111e** may be surrounded and mechanically integrated by a frame or the like.

The assembly **110** may constitute the optical element **11** without the louvers. In the case in which the optical element **11** is made of a single member, a molded member is continuously present from the upper portion to the lower portion in the region near the Z-axis **12** to constitute a thick portion. With this structure, the solidification time in molding increases, and the mass productivity is decreased. When manufacturing a plurality of separate parts having the end surfaces **115** along the X-Y plane, the thick portion is not formed, and the mass productivity can be increased. Further, the light-shielding plates disposed between joining surfaces of the parts can shield stray light, similarly to the louvers described above. Each part may have a recess portion in the joining surface (end surface) **115** according to the thickness of the light-shielding plate.

FIG. **31** schematically shows still yet another illumination device **1f**. FIG. **32A** is a schematic lateral view of the illumination device **1f**. FIG. **32B** is a schematic top view of the illumination device **1f**.

FIG. **33** is a schematic cross-sectional view of the schematic structure of the illumination device **1f** taken along the line XXXIII-XXXIII (see FIG. **32A**) along the center of the illumination device **1f**. FIG. **34** schematically shows an exploded view of the illumination device **1f** disassembled into parts. The illumination device **1f** includes the optical device **10** that converts the light (first light) **7** from the LED **6** serving as the light source into the illumination light **3** and emits the illumination light **3**, and the substrate **6a** on which the LED **6** that emits the first light **7** is mounted. The optical device **10** includes the first reflective surface **31** disposed to reflect, to a circular (cylindrical) first region around the first axis **12** as substantially collimated rays **71** in a direction perpendicular to the optical axis **7a** (first axis (Z-axis) **12**), at least a portion of the first light **7** incident along the first axis (Z-axis) **12** and having a Lambertian light distribution with the optical axis **7a** parallel to the first axis **12**; and the light-transmissive emission surface **15** adapted to refract at least a portion of the rays **71** reflected by the first reflective surface **31** to emit the rays around the first axis (Z-axis) **12**.

The illumination device **1f** further includes a part (axial light processing member) **120** that processes light traveling along the Z-axis **12**. The part **120** may be a light-shielding or reflective member so as to have substantially the same function as the control member **79** described above. The part **120** may have a function, such as the lens function and the light-diffusing function, of imparting optical performance as an illumination device. An illumination device that can illuminate not only the linear region but also a region

including a broad region around the axis direction of the cylindrical optical element may be provided. The part **120** may have a disk shape, a tube shape, a sphere shape, a quadrangular shape, or the like and may be a sculpture of a human, an animal, a plant, a building, or the like made of a light-transmissive or diffusing material.

The optical device **10** includes the optical element **11** that has the multilevel inner surface **16** including the TIR prisms **39** constituted of the coaxial reflective curved surfaces **31a** to **31e** centered on the first axis **12** and arranged along the first axis **12** and the transmissive surfaces **32a** to **32e** respectively corresponding to the reflective curved surfaces **31a** to **31e**; and the outer surface **15** including a tubular emission surface. The emission surface (outer surface) **15** of the optical element **11** in the present example is cylindrical, but the emission surface **15** may be a polygonal tubular surface that is polygonal in a cross section in a plan view (plane perpendicular to the first axis **12**) or may be a surface that has a continuous outline having a plurality of irregularities in a cross section. A cross section of the emission surface **15** in a direction along the first axis **12** may be a straight line or a surface having the periodic irregularities **40** or a plurality of inflection points **45** as described above.

Similarly to the optical element having the arc-shaped emission surface **15** described above, the optical element **11** includes the assembly **110** including a plurality of light-transmissive members (parts) **111a** to **111f** having end surfaces **115** perpendicular to the first axis **12**. Each of the parts **111a** to **111f** has an annular shape and includes an annular TIR prism **39** on an inner surface **16**, and its outer surface is an annular emission surface **15**. The light-shielding portion **117** may be provided on a portion or whole of the end surface **115** of each of the parts **111a** to **111f**, or the louvers **90**, which are light-shielding members, may be sandwiched between the parts **111a** to **111f** to constitute the assembly **110**.

The illumination device **1f** including the cylindrical optical element **11** is suitable for illumination of a linear region of a cylindrical surface (inner surface). Employing various shapes of the outer surface **15** of the optical element **11** in the illumination device **1f**, as described referring to FIG. 20A to FIG. 21C, allows for obtaining an illumination device appropriate for illumination of a polygonal tubular inner surface or an elliptic inner surface can be provided. The optical element **11** described above has a tubular shape or the shape of a portion of a tubular shape in appearance and is appropriate for illumination of a narrow linear or quadrangular region **2**. However, the optical element **11** may have a circular-conical shape or a shape of a portion of a circular cone or an egg-like shape or drum-like shape or a shape of a portion of these shapes suitable for illumination of a trapezoidal region **2** or illumination of a quadrangular or linear region **2** in a slant direction. Manufacturing and assembling the optical element **11** having a structure separated into a plurality of parts along the central axis (Z-axis) **12** enables provision of the optical element **11** having various shapes that collimates, in a direction perpendicular to the central axis **12**, the light **7** incident from the LED **6** along the central axis **12** using the reflective surfaces **31** and emits the light as the illumination light **3** appropriate for the shape of an illuminated region **2** using the refracting surfaces of the outer surface.

FIG. 35 schematically shows an illumination device **1g**, which is even yet another example of the illumination device. FIG. 36A is a schematic side view of the illumination device **1g**. FIG. 36B is a schematic top view of the illumination device **1g**. FIG. 37 is a schematic cross-sectional

view of the schematic structure of the illumination device **1g** taken along the line XXXVII-XXXVII (see FIG. 36A) along the center of the illumination device **1g**. FIG. 38 schematically shows the illumination device **1g** disassembled into parts.

The illumination device **1g** includes the optical device **10** that converts the light (first light) **7** from the LED **6** serving as the light source into the illumination light **3** and emits the illumination light **3**, and the substrate **6a** on which the LED **6** that emits the first light **7** is mounted. The optical device **10** includes the first reflective surface **31** disposed to reflect, to a circular (cylindrical) first region around the first axis **12** as substantially collimated rays **71** in a direction perpendicular to the optical axis **7a** (first axis (Z-axis) **12**), at least a portion of the first light **7** incident along the first axis (Z-axis) **12** and having a Lambertian light distribution with the optical axis **7a** parallel to the first axis **12**; the light-transmissive emission surface **15** adapted to refract at least a portion of the rays **71** reflected by the first reflective surface **31** to emit the rays around the first axis (Z-axis) **12**; a plurality of light-shielding louvers **90** protruded from the emission surface **15**; and the member **120** for processing light on the optical axis **7a**.

The optical device **10** includes the optical element **11** having the multilevel inner surface **16** including a plurality of TIR prisms **39**, the outer surface **15** including a tubular emission surface, and the louvers **90**. The optical element **11** includes the assembly **110** including the light-transmissive members (i.e., parts) **111a** to **111f** equivalent to the respective parts in the above example and having the end surfaces **115** perpendicular to the first axis **12**. The assembly **110** further includes the louvers **90** each disposed between the parts **111a** to **111f**. Each of the louvers **90** has a hollow disk shape, and includes the portions **91** for controlling stray light emitted from the emission surface **15** at an outer region of the optical element **11** and the portions **92** located between the parts **111a** to **111f** to shield stray light traveling between the parts **111a** to **111f**. Each of the light-transmissive members **111a** to **111f** may have a light-shielding portion **117** in an end surface **115** of each of the light-transmissive members **111a** to **111f** to shield stray light traveling between corresponding ones of the light-transmissive members **111a** to **111f** singly or in combination with the louvers **90**.

The illumination device **1g** including the cylindrical optical element **11** with the louvers is appropriate for illumination of, for example, a linear region of a cylindrical surface (inner surface). As described referring to FIG. 22 to FIG. 24, the illumination device **1g** may be provided with a circular cover over the upper and lower sides of the emission surface **15**. The illumination light **3** can be controlled by refraction by the emission surface **15** of the outer surface of the optical element **11** and by the louvers **90**, and the illumination light **3** can be emitted according to the shape of the region to be illuminated.

In the examples described above, the optical element **11** having the inner surface **16** including the first reflective surface **31** constituted by five or six separate reflective surfaces has been described, but the first reflective surface **31** may be constituted by four or less reflective surfaces or seven or more reflective surfaces. While the fan-shaped optical element **11** with a central angle (opening angle) θ of 90° has been described in the examples described above, the central angle θ may be 90° or less or 90° or more. The LED **6** used for the light source is not limited to a single LED **6**, but a plurality of LEDs of multiple emission colors may be used for the light source. Further, in the illumination device **1**, a plurality of optical devices **10** including a plurality of

optical elements **11**, or a plurality of projection units **5** may be arranged such that the Z-axes **12** are arranged in a row or such that the Z-axis **12** is shared.

One of the aspects disclosed above is an optical device that comprises: (a) a first reflective surface disposed to reflect, to a substantially arc-shaped first region around a first axis, at least a portion of first light incident along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis, the first reflective surface comprising a plurality of reflective arc surfaces separated in a direction along the first axis; (b) a second reflective surface and a third reflective surface intersecting each other on the first axis and disposed such that the first reflective surface is located between the second reflective surface and the third reflective surface; and (c) a light-transmissive emission surface adapted to refract at least a portion of light reflected by the plurality of reflective arc surfaces to emit the light around the first axis, the emission surface having periodic irregularities in a cross section in the direction along the first axis.

The emission surface may have at least one of the periodic irregularities in each of regions that face respective ones of the plurality of reflective arc surfaces in the cross section in the direction along the first axis. The emission surface may have a plurality of recesses or protrusions in each of regions that face respective ones of the plurality of reflective arc surfaces in the cross section in the direction along the first axis.

Another aspect disclosed above is an optical device that comprises: (a) a first reflective surface disposed to reflect, to a substantially arc-shaped first region around a first axis, at least a portion of first light incident along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis, the first reflective surface comprising a plurality of reflective arc surfaces separated in a direction along the first axis; (b) a second reflective surface and a third reflective surface intersecting each other on the first axis and disposed such that the first reflective surface is located between the second reflective surface and the third reflective surface; and (c) a light-transmissive emission surface adapted to refract light reflected by the plurality of reflective arc surfaces to emit the light around the first axis, the emission surface having a plurality of inflection points at a predetermined interval in a cross section in the direction along the first axis.

Each of the plurality of inflection points may be at least one of a changing point from a protrusion to a recess or from a recess to a protrusion, a changing point from a curved line to a straight line or from a straight line to a curved line, and a changing point of an inclination direction of a straight line. The emission surface may have at least two of the inflection points in each of regions respectively facing the plurality of reflective arc surfaces in the cross section in the direction along the first axis.

The plurality of reflective arc surfaces included in the optical device may comprise coaxial arc-shaped reflective surfaces centered on the first axis. The optical device may further comprise a control member adapted to inhibit direct incidence of a component of the first light on the optical axis into the first reflective surface. The emission surface may comprise a portion adapted to control a distribution around the first axis of light emitted through the emission surface. The optical device may further comprise a light-transmissive optical element substantially fan-shaped in a cross section perpendicular to the first axis.

The optical element may comprise a multilevel inner surface located inside the optical element, and the emission

surface located at an outer region of the optical element. The multilevel inner surface may include the plurality of reflective arc surfaces, and a plurality of transmissive surfaces each corresponding to a respective one of the plurality of reflective arc surfaces. The optical element may comprise an assembly of a plurality of light-transmissive members each having an end surface perpendicular to the first axis. The assembly may comprise the plurality of light-transmissive members each having the end surface at least partially comprising a light-shielding surface. The assembly may comprise a light-shielding member at least partially disposed between the plurality of light-transmissive members.

The optical device may further comprise a light-shielding mask over a periphery of the emission surface.

Yet another aspect of the above is an illumination device that comprises the optical device according to the above and a light source adapted to emit the first light.

Yet another aspect disclosed above is a light-transmissive optical element that comprises a multilevel inner surface. The multilevel inner surface comprises a plurality of coaxial reflective curved surfaces disposed along a first axis and centered on the first axis, and a plurality of transmissive surfaces respectively corresponding to the plurality of reflective curved surfaces. The light-transmissive optical element further comprises an outer surface comprising a tubular or arc-shaped emission surface, and an assembly of a plurality of light-transmissive members each having an end surface perpendicular to the first axis. Each of the plurality of light-transmissive members has a portion of the inner surface of the optical element and a portion of the outer surface of the optical element.

The assembly may comprise the plurality of light-transmissive members each having the end surface at least partially comprising a light-shielding surface. The assembly may comprise a light-shielding member at least partially disposed between the plurality of light-transmissive members. The light-shielding member may comprise a portion extending out from the outer surface. Each of the plurality of light-transmissive members may have at least one set of a corresponding one of the plurality of reflective curved surfaces and a corresponding one of the plurality of transmissive surfaces. Each of the plurality of light-transmissive members may have a corresponding one of the plurality of reflective curved surfaces and a corresponding one of the plurality of transmissive surfaces. Each of the plurality of reflective curved surfaces may be configured to reflect, around the first axis, a portion of first light incident from a first side of the first axis along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis.

Yet another aspect of the above is an illumination device that comprise: the optical element according to the above; and a light source adapted to emit the first light. The illumination device may further comprise a second reflective surface and a third reflective surface, wherein the plurality of reflective curved surfaces constitutes the first reflective surface, the second reflective surface and the third reflective surface intersect each other on the first axis on both sides of the first reflective surface, and the optical element has the arc-shaped emission surface.

It is to be understood that although certain embodiments of the present invention have been described, various other embodiments and variants may occur to those skilled in the art that are within the scope and spirit of the invention, and such other embodiments and variants are intended to be covered by the following claims.

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The invention claimed is:

1. An optical device comprising:

a first reflective surface disposed to reflect, to a substantially arc-shaped first region around a first axis, at least a portion of first light incident along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis,

the first reflective surface comprising a plurality of reflective arc surfaces separated in a direction along the first axis;

a second reflective surface and a third reflective surface intersecting each other on the first axis and disposed such that the first reflective surface is located between the second reflective surface and the third reflective surface; and

a light-transmissive emission surface adapted to refract at least a portion of light reflected by the plurality of reflective arc surfaces to emit the light around the first axis,

the emission surface having periodic irregularities in a cross section in the direction along the first axis.

2. The optical device according to claim **1**, wherein the emission surface has at least one of the periodic irregularities in each of regions that face respective ones of the plurality of reflective arc surfaces in the cross section in the direction along the first axis.

3. The optical device according to claim **1**, wherein the emission surface has a plurality of recesses or protrusions in each of regions that face respective ones of the plurality of reflective arc surfaces in the cross section in the direction along the first axis.

4. The optical device according to claim **1**, wherein the plurality of reflective arc surfaces comprise coaxial arc-shaped reflective surfaces centered on the first axis.

5. The optical device according to claim **1**, further comprising a control member adapted to inhibit direct incidence of a component of the first light on the optical axis onto the first reflective surface.

6. The optical device according to claim **1**, wherein the emission surface comprises a portion adapted to control a distribution around the first axis of light emitted through the emission surface.

7. The optical device according to claim **1**, comprising a light-transmissive optical element substantially fan-shaped in a cross section perpendicular to the first axis, the optical element comprising:

a multilevel inner surface located inside the optical element, the multilevel inner surface comprising:

the plurality of reflective arc surfaces; and

a plurality of transmissive surfaces each corresponding to a respective one of the plurality of reflective arc surfaces, and

the emission surface located at an outer region of the optical element.

8. The optical device according to claim **7**, wherein the optical element comprises an assembly of a plurality of light-transmissive members each having an end surface perpendicular to the first axis.

9. The optical device according to claim **8**, wherein the assembly comprises the plurality of light-transmissive members each having the end surface at least partially comprising a light-shielding surface.

10. The optical device according to claim **8**, wherein the assembly comprises a light-shielding member at least partially disposed between the plurality of light-transmissive members.

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11. An optical device comprising:

a first reflective surface disposed to reflect, to a substantially arc-shaped first region around a first axis, at least a portion of first light incident along the first axis and having a light distribution characteristic with an optical axis parallel to the first axis, the first reflective surface comprising a plurality of reflective arc surfaces separated in a direction along the first axis;

a second reflective surface and a third reflective surface intersecting each other on the first axis and disposed such that the first reflective surface is located between the second reflective surface and the third reflective surface; and

a light-transmissive emission surface adapted to refract light reflected by the plurality of reflective arc surfaces to emit the light around the first axis,

the emission surface having a plurality of inflection points at a predetermined interval in a cross section in the direction along the first axis.

12. The optical device according to claim **11**, wherein each of the plurality of inflection points is at least one of a changing point from a protrusion to a recess or from a recess to a protrusion, a changing point from a curved line to a straight line or from a straight line to a curved line, and a changing point of an inclination direction of a straight line.

13. The optical device according to claim **11**, wherein the emission surface has at least two of the inflection points in each of regions respectively facing the plurality of reflective arc surfaces in the cross section in the direction along the first axis.

14. The optical device according to claim **11** further comprising a light-shielding mask over a periphery of the emission surface.

15. The optical device according to claim **11**, wherein the plurality of reflective arc surfaces comprise coaxial arc-shaped reflective surfaces centered on the first axis.

16. The optical device according to claim **11** further comprising a control member adapted to inhibit direct incidence of a component of the first light on the optical axis onto the first reflective surface.

17. The optical device according to claim **11** wherein the emission surface comprises a portion adapted to control a distribution around the first axis of light emitted through the emission surface.

18. The optical device according to claim **11**, comprising a light-transmissive optical element substantially fan-shaped in a cross section perpendicular to the first axis, the optical element comprising:

a multilevel inner surface located inside the optical element, the multilevel inner surface comprising:

the plurality of reflective arc surfaces; and

a plurality of transmissive surfaces each corresponding to a respective one of the plurality of reflective arc surfaces, and

the emission surface located at an outer region of the optical element.

19. An illumination device comprising:

the optical device according to claim **1** and a light source adapted to emit the first light.

20. An illumination device comprising:

the optical device according to claim **11** and a light source adapted to emit the first light.

21. A light-transmissive optical element comprising:

a multilevel inner surface comprising:

a plurality of coaxial reflective curved surfaces disposed along a first axis and centered on the first axis, and

a plurality of transmissive surfaces respectively corresponding to the plurality of reflective curved surfaces; and
an outer surface comprising a tubular or arc-shaped emission surface,⁵
the optical element comprising an assembly of a plurality of light-transmissive members each having an end surface perpendicular to the first axis,
wherein each of the plurality of light-transmissive members has a portion of the inner surface of the optical element and a portion of the outer surface of the optical element.¹⁰

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